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Natural Ventilation Studies within the EC PASCOOL Joule II Project

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Introduction

As revealed by the last ZEPHYR competition (1), natural ventilation is the first design strategy used by architects or designers to reduce building cooling loads and improve indoor comfort in Mediterranean countries where air conditioning systems do not represent a systematical and realistic alternative. Unfortunately, if the effects of natural ventilation on the energy balance of a room or on the perceived comfort of the occupant have been extensively described and can be experienced by anyone, the prediction and design of natural ventilation and its integration in building design as a passive cooling strategy is not really well dominated. In order to fill these existing gaps, natural ventilation phenomena have been extensively studied in the framework of the PASCOOL research project (2). The coordinated efforts of research groups from Belgium (BBRI), France (University of La Rochelle and ENTPE), Greece (University of Athens), Italy (University of Milano), Portugal (University of Porto), Spain (University of Malaga) and Switzerland (EPFL) have made this PASCOOL task one of the most significant contributions to natural ventilation studies in the recent years.

Aims and Strategies of the Ventilation PASCOOL Task

Based on a huge experimental programme, various different aspects of the problem were covered during the PASCOOL project:

- single sided ventilation

- cross ventilation

In this issue

- airflow through large openings

- night ventilation and the coupling with thermal mass.

More than a hundred single sided and cross ventilation experiments were performed in various buildings and test cells located in different countries in Europe. In order to evaluate the ventilation flow rates, experimental techniques using tracer gases have been experienced and tested in natural ventilation configuration as well as energy balance approaches. Various geometrical and climatic configurations have been tested. Combined ventilation and thermal mass experiments have also been performed to study air flow patterns in multizone buildings presenting important stack effects.

Various models have also been tested in order to predict natural ventilation air flows in buildings. New models resulting from the experiments have been proposed and integrated in a new air flow model PASSPORT-Air based on a network approach. In order to feed this code with realistic data, the group has developed CPCALC+ (3) a new method predicting the pressure coefficients on building surfaces for various shapes of building and roofs. Wind tunnel experiments using three boundary layer profiles have been used to obtain regression curves for the determination of the pressure coefficient distribution.

Finally a new approach using zonal modelling has been proposed in order to assess air flow patterns in naturally ventilated rooms.

Final Products and Main Results of the PASCOOL Natural Ventilation Task

All the results of the Ventilation task are presented in the «Ventilation-Thermal Mass Subtask Final Report» (2) organised into six chapters describing the contributions of the PASCOOL Group to the various aspects of natural ventilation. In this short presentation, we will focus on three main contributions, Single Sided Ventilation, Cross Ventilation and Air Flow Modelling.

Single Sided Ventilation

Single sided ventilation experiments were carried out in real buildings located in Athens, Madrid and Lyon, and in fully equipped test cells . Two of them in Athens and BBRI were developed within the frame of the PASSYS Project. A third one located in Porto has also been used. Most of the experiments were performed using tracer gas decay techniques.

A total of 76 experiments were performed in Greece composing the largest data base on single sided ventilation. From this data base, a model has been proposed introducing a correction factor, CF by which the theoretical flow equations of the network model have to be multiplied to give more realistic results. Furthermore, a correlation giving CF in terms of thermal and flow characteristics has been proposed.

$$CF = 0.08\,(Gr / Re^2_D)^{-a.38} \quad (1)$$

With Gr: Grashof number calculated on the height of the opening and the reference temperature difference, and Re_D, Reynolds number calculated using the reference velocity and the depth of the cavity.

This model has been validated using the results of other single sided ventilation and it is convenient when the inertial flow due to wind speed is the driving phenomenon. In the case of higher temperature differences between outdoor and indoor conditions, experiments carried out by BBRI in Belgium have demonstrated that a multi term model is more efficient. This model takes into account each physical contribution to the air flow by means of a new formulation.

$$Q = \sqrt{Q^2_{network}(Cd, \Delta T) + (\alpha A V)^2 + (\beta A)^2} \quad (2)$$

With $Q_{network}$ air flow rate calculated by the network model using Cd = 0.66, A opening area (m^2), V Wind speed (m/s), α, β wind and turbulence parameters related to investigated environment

It has also been shown in the BBRI experiments that the heterogeneity of the concentration field is an important source of uncertainty when evaluating air flow rates

Air
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Editor: Janet Blacknell

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Conclusions and opinions expressed in contributions to Air Infiltration Review represent the author(s)' own views and not necessarily those of the Air Infiltration and Ventilation Centre.

due to natural ventilation. A thermal balance of the room is certainly, when possible, a more accurate way.

Indeed, as said before, these models are certainly limited to a reduced number of conditions (wind direction, wind speed and temperature differences), and further investigation is now needed to extend their applicability domain.

Cross Ventilation

From a literature review, various models have been investigated

Global air flow rate prediction

Aynsley's Model (1977) (4)

Vickery's Model (1987) (5)

Global resistance approach (Aynsley 1988) (6)

Virtual Stream tube method (Murakami 1991) (7)

Velocity Coefficient Approaches

Gouin (1984) (8)

Givonni (1988) (9)

Ernest (1991) (10)

This review shows that there is a wide range of uncertainty in these various models. In most cases the applicability limits are not well described, and they can be very difficult to extend to general cases.

In order to study a wide range of configurations, different experimental facilities have been used in Belgium, Greece, Spain and Switzerland. The resulting experiments were carried out using either constant injection or decay methods.

Single zone and two zone experiments carried out in Athens used the Aynsley model to identify the discharge coefficient of the openings. A low value of .2 has been identified and does not seem to be influenced by the thermal conditions. In these experiments, the mixing of the tracer gas was found to be very good. This result is surprising and disagrees with Murakami's description of an inertial flow crossing the room.

On the contrary, the experiments carried out in Mendillory building in Spain showed a real difficulty in assessing a good homogeneity of the tracer gas in cross ventilation configuration. In this case, the decay method appears to be more appropriate than the constant injection.

Givonni's model giving the mean velocity within the cell has also been used in order to propose various correlations. Nevertheless, the whole experience of cross ventilation studies carried out during the PASCOOL Project clearly shows that specific experimental facilities are now necessary to go a step further. The boundary conditions have to be controlled very carefully in order to give a strict indication of the limits of applicability of the various existing models.

Air Flow Predictions

During the PASCOOL Project, the modelling activities were split into two main contributions. On the one hand, a multizone air flow model PASSPORT-Air adapted to natural ventilation conditions has been developed and evaluated through the large experimental PASCOOL data base. On the other hand, a new approach using zonal modelling has been investigated. PASSPORT-Air is based on a nodal concept, each zone of a building is represented by a pressure node. Boundary nodes are also representing the outside environment, and flow equations are used to calculate the air flows through each flow path. Cracks, windows, doors and shafts are considered, and special care has been devoted to the prediction of natural ventilation flows.

This model has been evaluated by comparison with five other airflow models, namely ESP, COMIS, BREEZE, AIRNET, and NORMA. Almost similar airflow rates are predicted by all tools when assuming regular air flow equations as shown in Table 1. Nevertheless the introduction of the Correction Factor significantly improves the accuracy of the prediction. The correlation coefficient between experimental values and numerical prediction goes from 0.4 without CF to 0.75 with CF correction. Figure 1 presents this result. Further validation of the model is obviously necessary to confirm this result, and special care in cross ventilation prediction will be required.

The limits of airflow network models are well known. While they can predict the air flow rates between the zones of a building and the outdoors, they are not able to give any information about airflow patterns and velocity field within the rooms although these data are obviously necessary when dealing with comfort prediction or natural ventilation efficiency. CFD codes could be used for this purpose, however they are very heavy to use and the results are sometimes questionnable when using a limited number of nodes or wall functions. An intermediate concept has been developed over few years introducing an empirical description of a cavity in dominant flows: boundary layers, jets or plumes. These flows can be described by analytical functions or empirical correlations and mass balance and energy bal-

Tool	ESP	PASSPORT AIR	AIRNET	COMIS	NORMA	BREEZE
Passport	0.99	1.00	0.98	1.00	0.98	0.99
AIRNET	0.98	0.98	1.00	0.98	0.93	0.99
COMIS	0.99	1.00	0.98	1.00	0.98	0.99
NORMA	0.98	0.98	0.93	0.98	1.00	0.96
BREEZE	0.99	0.99	0.99	0.99	0.96	1.00
ESP	1.00	0.99	0.98	0.99	0.98	0.99

Table 1: Correlation coefficients for inter model comparison

ance in each zone of the room are then sufficient to predict air flow patterns and heat flows (12). During the PASCOOL Project this concept has been used in order to predict natural ventilation flow patterns within a room. The results obtained in comparison with those of CFD prediction are encouraging and further research in this field is very promising.

Conclusion

A large research effort in the field of natural ventilation has been carried out during the PASCOOL E.C. Project. Various aspects of the problem such as single sided ventilation, cross ventilation, airflow prediction, night ventilation or large internal openings have been studied, and an important confrontation of experimental knowledge and theroretical analysis has led to a real improvement of experience in this domain. Nevertheless, necessary studies have also been identified in order to improve the description of outdoor conditions around buildings and of heterogeneous indoor environment. Furthermore, another important effort is also necessary to transform the scientific knowledge acquired during such a project into efficient design tools and guidelines for architects and engineers.

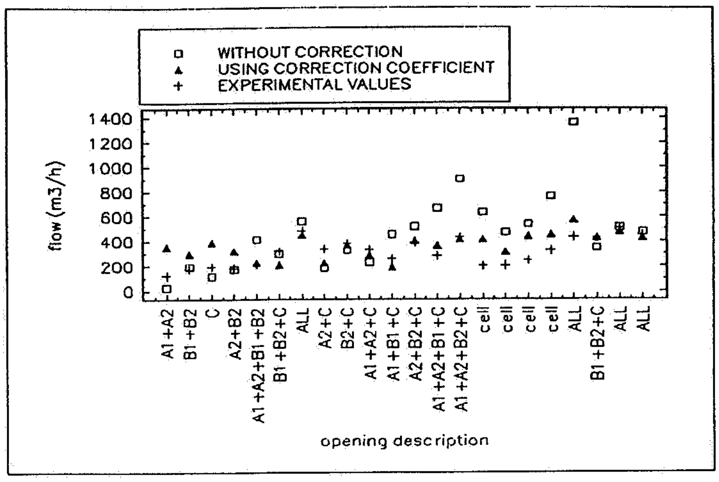

Figure 1: Comparison of numerical predictions with experimental results

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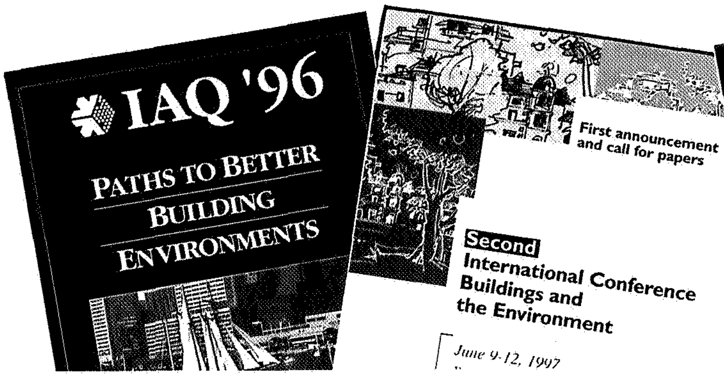
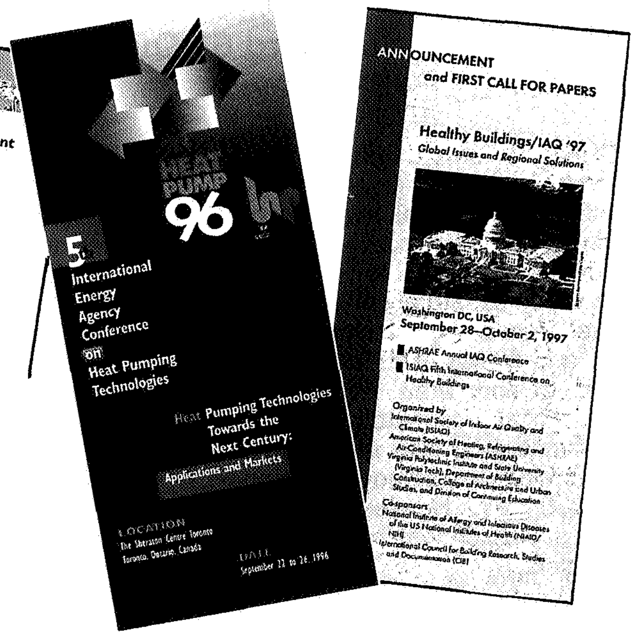
Forthcoming Conferences





Heat Pump '96
5th International Energy Agency Conference on Heat Pumping Technologies
September 22-26 1996
The Sheraton Centre Toronto, Ontario, Canada
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IAQ '96 Paths to Better Building Environments
6-8 October 1996
Baltimore, Maryland, USA
Ashrae Meetings 1791 Tullie Circle, NE Atlanta, GA 30329 USA
Tel: 404 636 8400
Fax: 404 321 5478

ISBE International Society of the Built Environment Hospital Air Quality and Infection Control
10-11 October 1996
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Fax: +90 312 467 0885

PLEA 1997 Kushiro
The 14th International Conference on Passive and Low Energy Architecture - Bioclimatic Design in Cold Climates
January 8-10 1997
International Conference Hall, Kushiro, Japan
Contact: Secretariat, PLEA 1997 Kushiro Conference, Kenchikukaikan 3F, Shiba 5-26-20, Minato-ku, Tokyo, 108 Japan
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CIB TG8
Second International Conference Buildings and the Environment
9-12 June 1997
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Clima 2000 '97
August 30 - September 2, 1997
Brussels, Belgium
Contact:
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ISBE Indoor and Built Environment Problems in Asia
4-5 September 1997
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Dr H H Lim Medviron Consultants Sdn Bhd 257-2 Jalan Tun Sambanthan 50470 Kuala Lumpur Malaysia

Healthy Buildings/IAQ '97
Global Issues and Regional Solutions
September 28-October 2, 1997
Washington DC, USA
Prof James E Woods
Virginia Polytechnic Institute and State University
2990 Telestar Court
Falls Church, VA 22042, USA

Indoor Air 99 The 8th International Congress on Indoor Air Quality and Climate
8-13 August 1999
Edinburgh, UK
Prof G J Raw (Indoor Air 99) Building Research Establishment Watford WD2 7JR UK
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News, Books and Product Developments

ASHRAE Standard 62 Out for Public Review

ASHRAE Standard 62 on Minimum Ventilation for Acceptable Indoor Air Quality has become the 'Model' for ventilation standards in many countries. The latest revision is currently undergoing public review. Included is a proposed change to the specification of ventilation rate which separately takes into account pollutant generated from occupants and that generated from furnishings and fittings. This is quoted at 3.0 l/s.p and 0.35 l/s.m^2 of floor area. Assuming an office occupation density of approximately 10 m^2/occupant, the per occupant ventilation rate amounts to about 6.5 l/s.p and corresponds to a steady state indoor CO_2 concentration of 1000 ppm. However, in more densely occupied spaces, CO_2 concentrations of up to 2000 ppm can be expected.

For more information: Copies of the public review document are available from Ashrae Customer Service at 800-5-Ashrae (US and Canada) or 404 636 8400 (worldwide), Fax 404 321 5478, 1791 Tullie Circle, NE, Atlanta, GA 30329, USA, and comments are needed by 12th December 1996.

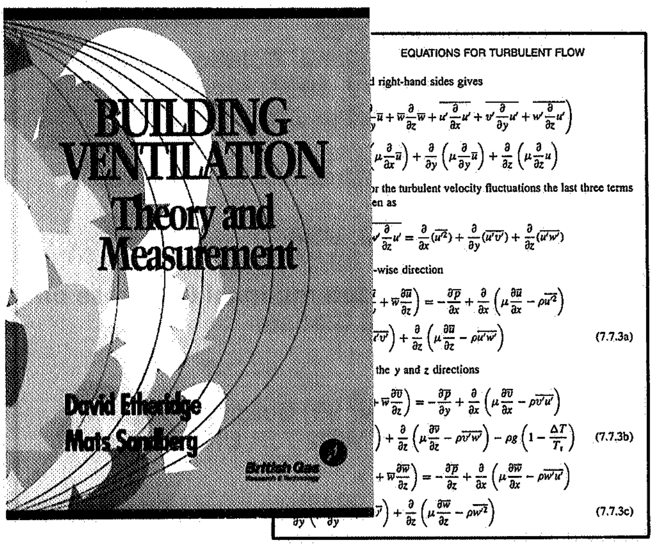
For pilot test purposes, the draft will be available by August 15th free of charge through the ftp site at ftp.ashrae.org in the directory Standard, filename 62DRAFT.EXE.

New Text Book on Ventilation

"Building Ventilation: Theory and Measurement"

by David Etheridge and Mats Sandberg

764 pp, ISBN No: 0471 96087 X, Published by John Wiley and Sons, price £65 Sterling +£3 post and packing.



Both David Etheridge and Mats Sandberg are well known for their pioneering work in improving the theoretical understanding of ventilation and air movement in buildings. This comprehensive presentation details the knowledge they have gained during the course of their research. It focuses on fundamentals and theory and is therefore deeply mathematical. Topics cover mechanisms, flow through envelope openings, mathematical models, mass transport, mixing, momentum, buoyancy, air flow in rooms, flow through large openings, experimental techniques for evaluating flow characteristics, multi-zone representation of buildings, tracer gas methods for ventilation and age of air evaluation, scale models and computational fluid dynamics. It also considers both natural and mechanical ventilation. This textbook represents a definitive account of the theory and measurement of ventilation and should be suitable for anyone who requires a good numerical outline of the topic. (MWL)

For ordering and more information contact: Jo Shawyer (phone) +44 (0)1243 843206, (fax) +44 (0)1243 770225.

Inexpensive Ventilation Pre-heat Absorbs in Excess of 60% of Solar Energy

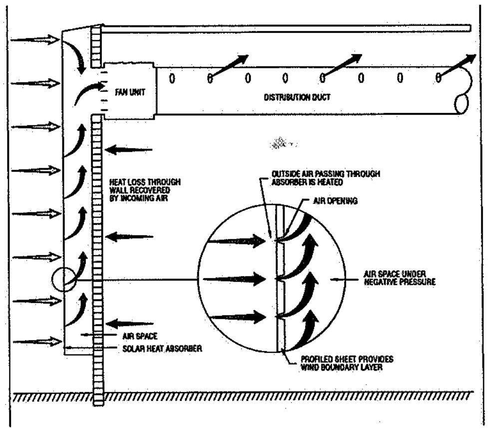
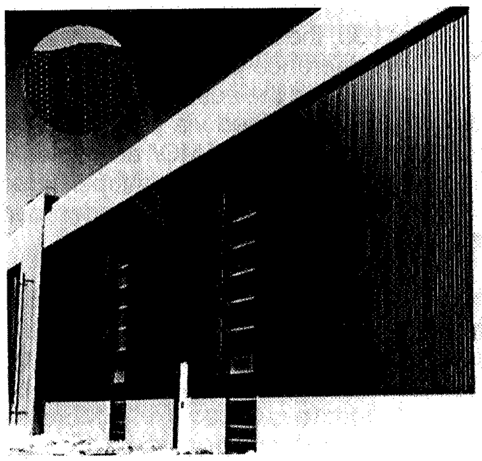


Illustration of Solarwall concept

The United States National Renewable Energy Laboratory (NREL) in Golden, Colorado, in conjunction with Conserval Systems Inc, in Buffalo, NY have developed a solar collector which pre heats incoming ventilation air by as much as 30°C. It consists of a dark corrugated perforated sheet that is mounted several centimetres from a sun facing wall. The dark panel absorbs solar radiation and heats incoming air drawn through its perforations into a plenum. Heat escaping from the building is also captured in this plenum. Solar heat transfer has been maximised by optimising the air flow rate, and the spacing and size of the perforations. The simplicity of this product ensures reliability and ease of production. Above all it does not contain any of the complexities of earlier solar panels.

The system has been demonstrated in a wide variety of buildings. In cold climates it takes advantage of both direct and diffuse solar radiation to provide pre-heat, while in warm climates, especially in developing areas, it has important applications in crop drying. The 'Transpired Solar Collector' has been recognised by the United States Department of Energy's, 'Energy Related Inventions Program' as being among the top 2% of energy inventions. It also features DOE's R&D 100 award.



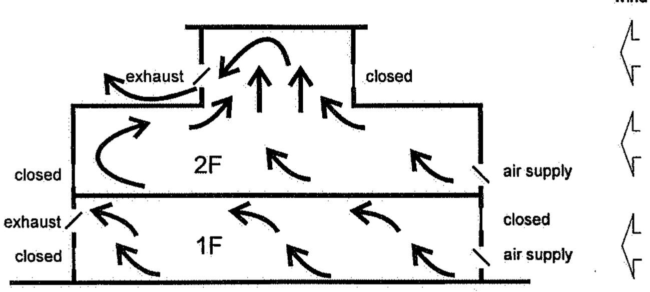
For further information contact:

Charles Kutscher (NREL) +1 (303) 275 6024

John Hollick (Conserval Engineering Corp) +1 (416) 661 7057

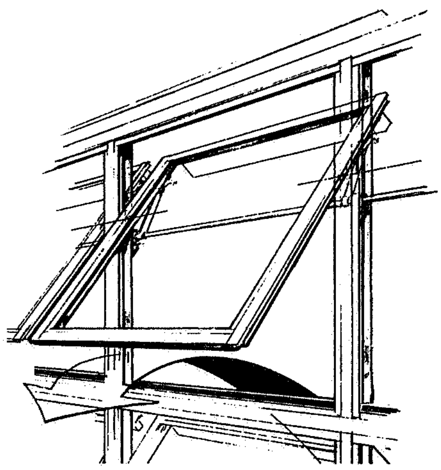
'Swing' Window Provides Uniform Air Flow Rate

From Japan comes the 'Swindow'. This is a counterbalanced openable window that responds to pressure difference, thus allowing an almost constant air flow rate irrespective of driving force. Both exhaust and supply versions are available. It is recommended that supply windows are set in the lower part of opposite walls, while exhaust windows are placed in the upper part of the same walls (see Figure). Irrespective of the nature of the driving force or the direction of wind, a cross flow or stack flow ventilation pattern will be established.



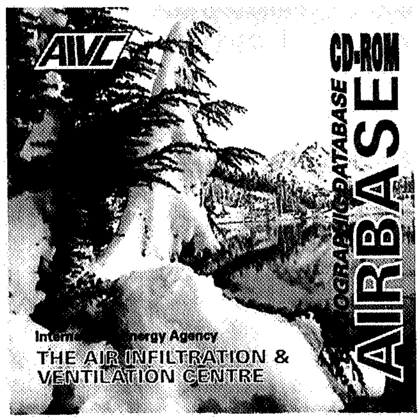
For more information contact: Mr Nomura or Mr Ebitani by fax on +81 766 20 3385

Tateyama Aluminium Industry Co., Ltd.



AIRBASE Available on CD-ROM

AIRBASE, the AIVC's bibliographic database is now available on CD-ROM. Both DOS and Windows versions are included and it is possible to either operate AIRBASE directly from a CD Drive or download the software onto hard disk. This new version greatly simplifies installation and operation by eliminating the need for many compressed floppy disks.



AIRBASE presently contains over 10,000 fully abstracted references to technical papers and articles related to ventilation. Topics cover strategies, measurement and calculation methods, energy implications and indoor air quality. Input is derived from literature published throughout the world and from conference proceedings and reports from government and other laboratories. It is updated quarterly with titles and bibliographic details being summarised in 'Recent Additions to AIRBASE'. Abstracts of the most recent items are published on the World Wide Web at http://www.aivc.org/

Existing users can opt to receive the CD version as future updates at no increase in charge. It will also be available to new users (in participating Countries) from September at £150 Sterling plus UK VAT where applicable, inclusive of postage and packing. Subsequent updates can be supplied annually at £60 + VAT, or four per year at £120 +VAT.
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Sensitivity Analysis for Modelers

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Introduction

This short article aims to inform modellers and model users about efficient sensitivity analysis methods. Also presented is a tool under development aimed at simplifying the application of sensitivity methods. Such techniques are essential to add confidence to numerical prediction. Too often, simulation data are presented without any error bars and any information on their accuracy. They are obtained with a single run of the model, and the influence of the input uncertainty is ignored. Sometimes, although less often, a one-parameter-at-a-time sensitivity analysis is performed, requiring a relatively long time and providing no indication of interactions and unsuspected effects.

It is important to understand that efficient methods exist for sensitivity analysis and that they are widely used in such fields as environmental risk analysis, economics, and the aircraft, nuclear and defence industries. In those fields, modellers are required to verify their results with sensitivity and error analyses [6].

Techniques

It is a challenge for modellers to distribute models which cannot be misused too easily. This means asking the user about the uncertainty of the input, calculating confidence intervals, providing means to perform sensitivity and error analysis, and addressing these topics in the user manual and in simulation reports. It can also mean including a specialist on sensitivity analysis in the development team.

One of the arguments used to justify the avoidance of sensitivity analysis is that the problem has too many input parameters. This can be overcome by using techniques such as the 'Monte Carlo' which is capable of being used to calculate confidence intervals in one hundred runs for any number of varying input parameters (±14% accuracy if Gaussian hypothesis is valid) [3,10]. Plackett and Burman designs exist which allow users to calculate all main effects of N parameters with N+1 runs, for N up to 100 or more [15]. Sobol method exists which makes possible apportionment of the linear and nonlinear sensitivity between parameters or groups of parameters [8,19]. Sequential bifurcation exists which screens important effects with a small number of runs much smaller than the number of varying parameters (i.e. 136 runs to extract 23 major parameters from 390) [16,17]. For parametric or optimization studies, statistical techniques are available which minimize the number of simulations. They are usually based on surface response techniques [11].

In September 1995, the SAMO (Sensitivity Analysis of Model Output) conference in Belgirate was dedicated to those techniques and their use in different fields. The proceedings can be obtained via the Internet by connecting to http://rea.ei.jrc.it/SAMO/ and down-loading files [18]. Further information on this topic can also be located on the WWW by searching under 'sensitivity analysis'.

A common starting point is the textbook by Box et al. on design of experiments [1]. The use of experimental design in simulation was initiated by Naylor in 1969 [14]. Several textbooks on simulation introducing classical techniques are also available [9,11]. More sophisticated and also recent techniques are published in the following journals:

- *American journal of Mathematical and Management Sciences*
- *Biometrica*
- *Communication in statistics (Theory and Method)*
- *Communication in statistics (Simulation and Computation)*
- *Communication ACM*
- *Computational statistics and data analysis*
- *Computer in physics*
- *European journal of operational research*
- *Journal of statistical computation and simulation*
- *Journal of mathematical physics*
- *Journal of quality technology*
- *Management sciences*
- *Mathematics and computers in simulation*
- *Reliability engineering and system safety*
- *Simuletter*
- *Simulation*
- *Tecnometrics*

This list is not at all comprehensive but few are read by building physics practitioners. It is very difficult to keep track of what is going on in secondary subjects, especially in statistics because the vocabulary is sometimes different, and extracting practical information is not straightforward. Key papers are surveys of the subject by J.C. Helton, T. Turanyi or J. Kleijnen which contain many valuable pointers [7,20,13].

As part of IEA Annex 23 'Multizone air flow modelling', an important effort was targeted on the problem of simulation confidence. This addressed experimental as well as user-introduced uncertainty. The final report contains theoretical points, techniques and several case studies [2,5], thus representing a good introduction to the subject of sensitivity analysis for ventilation practitioners.

MISA (Multirun Interface for Sensitivity Analysis)

In practice tools are needed which are efficient but at the same time are good tutorials. One such tool, known as MISA (Multirun Interface for Sensitivity Analysis) is currently being developed at NIST. It is a Windows version of a tool developed as part of Annex 23. The aim of this software is to provide practitioners with a way to use up-to-date statistical methods for simulation and to allow them to perform a sensitivity analysis within a couple of hours. MISA is designed for encapsulating a DOS or a UNIX modelling program that works in batch mode with unformatted input and output file(s). The computation procedure follows [4]:

1. The project file (the input file representing the project under study) is flagged to point the parameters to be studied and becomes a reference file
2. The ranges of the parameters to be varied are entered
3. Depending on the type of statistical method to be used, a design consisting of a special matrix of standardized values is selected. The design matrix has one line per simulation run and one row per parameter to be varied
4. A new input file is generated by processing the reference file, the range information and a line of the design matrix. The new input file is run.
5. Step 4 is repeated as many times as necessary to complete the design
6. Numerical treatments such as mean, standard deviations and correlation coefficients or meta-model regression are applied to the output to extract the sensitivity indices or uncertainty information related to the selected statistical technique.

The general idea of the interface (see Figure 1) is to represent the flow of information during the multirun process and, within this scheme, to provide the user with tools to perform analyses. The graphical interface, making the structure evident, gives the user easy access to the multirun facility, and he can then spend more effort on the statistical strategy to follow and the analysis of the results.

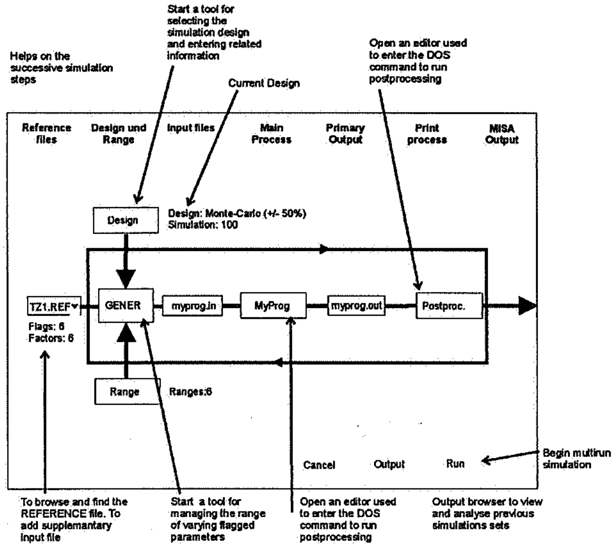

Figure 1: Main window of MISA (Multirun Interface for Sensitivity Analysis). It is a graphical representation of the flow of information during the procedure. The user enters commands through push buttons and pop-up menus which are placed into the scheme according to their influence. Help windows are available which explain the main point of each step of the procedure.

Conclusions

Simulation work should incorporate a sensitivity analysis indicating the confidence limits of output data. This can be done efficiently by using up-to-date statistical techniques as it is done in others fields. There are many such techniques, and a statistical handbook for simulation could be of great help.

Sensitivity Analysis must be considered when developing models and user interfaces as well as when beginning a new study. To assist this approach, MISA will be available very soon.

For further information please contact the author, who has a 'beta' version of MISA under evaluation.

Acknowledgements

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Two Air Flow Studies Completed

Martin Liddament reviews two recently completed air flow annexes

Introduction

Ultimately, the quality of indoor air and thus the health of occupants is dependent on the interaction and mixing behaviour of pollutants with clean air. In addition, the heating and refrigerative cooling of a space is exceptionally energy intensive with the result that unnecessary or uncontrolled air flow from buildings still results in a largely undefinable but significant proportion of total energy loss. Only by continuing to develop measurement and calculation techniques, and by producing practitioner tools, can energy efficient solutions to indoor environmental problems be achieved.

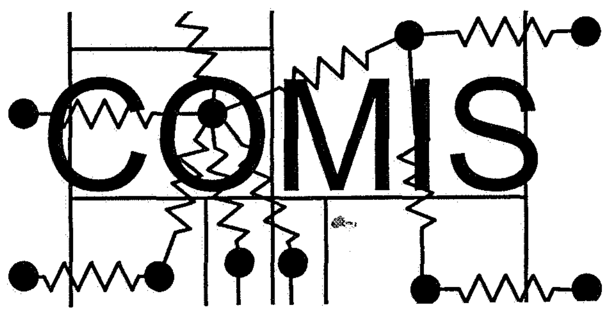
In its strategy plan for 1994 to 1997, the IEA Executive Committee for Energy Conservation in Buildings and Community Systems (ECBCS) concluded that ventilation and air movement will become the dominant heat and cooling loss mechanism in buildings of the next century. Its impact on global energy use will also increase substantially. Thus a goal was established to determine indoor air quality and optimal ventilation needs and to identify alternative energy efficient strategies to control the indoor environment. In support of this, various research annexes were established including:

- Annex 23 Multi-Zone Air Flow Modelling
- Annex 26 Energy Efficient Ventilation of Large Enclosures

These annexes have now been completed and the results were presented at the recent Roomvent Conference held in Yokohama, Japan on 17th-19th July 1996. A review of the outcome is summarised below.

Annex 23 Multi-Zone Air Flow Modelling (COMIS)

Background and Objectives



Having its origins as a year long international workshop held at the Lawrence Berkeley Laboratory in California, the 'Conjunction Of Multizone Infiltration Specialists' (COMIS) became adopted as IEA Annex 23 in 1992. The Operating Agent responsible for the development and management of this task is Dr Helmut Feustel of the Energy and Environment Division of the LBL. Its focus was to develop a new multi-zone (inter-room) air flow and pollutant transport model. In support of this, the task also involved the most comprehensive evaluation of such models ever attempted. This activity attracted the co-operation of researchers from nine countries, it included the intercomparison of many existing models and involved measurements made in more than a dozen buildings and structures. While currently not widely used, multi-zone models are invaluable for predicting the pattern of air flow and pollutant migration throughout an entire building. They have also been applied to the prediction of air flow in a single enclosed space (Annex 26). Further applications include evaluating the performance of ventilation systems, identifying the impact on air flow and air change rate of window or vent opening, and predicting flow rates in mechanical or natural ventilation ducts. Additionally, they may be coupled to thermal models to provide a much more accurate evaluation of heat loss and temperature distribution than is possible by simply assuming a fixed air change rate or ventilation duty cycle.

The Tasks

Tasks included:

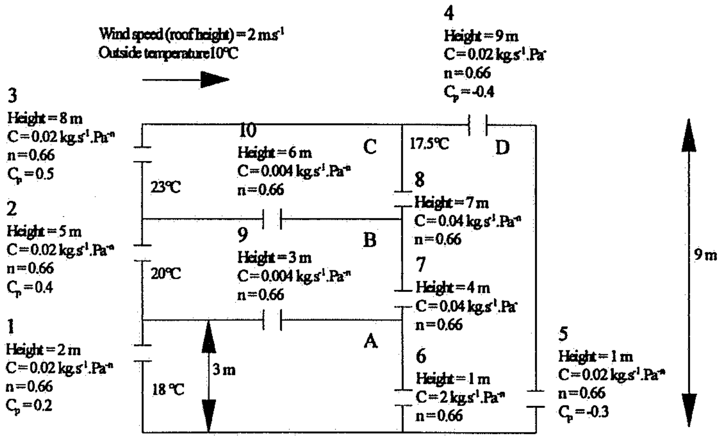
- devising a robust algorithm incorporating the fundamental features of interzonal air and pollutant flow.
- developing a user friendly interface.
- evaluating the algorithm for numerical reliability.
- evaluating potential user difficulties.
- comparing numerical prediction with experimental data.

The Algorithm

COMIS is designed to solve a network of equations representing air flow between individual rooms or zones within a building and between the inside and outside of a building. It is modular in concept and contains algorithms to handle many flow problems including flow through cracks, large openings, vertical openings, ductwork and natural and mechanical ventilation systems. It also evaluates pollutant migration and pressure distribution. In principle, further modules covering other aspects may be added as the need arises. Mass air flow rates are solved for known air path distributions and for mechanical and natural driving forces.

The User Interface

Two user interfaces have been developed to aid the input of data. The first, 'COMERL', is DOS based and has been developed at EMPA in Switzerland as a simple tool to complement COMIS. The second is a totally interactive Windows based graphical interface, 'IISIBat' which has been developed at the Centre Scientifique et Technique du Batiment (CSTB), France. This latter version introduces considerable transparency into the operation of COMIS and very much relieves the user of the need to understand the COMIS program. Both interfaces have provision for 'default' information, including data from the AIVC's numerical database.



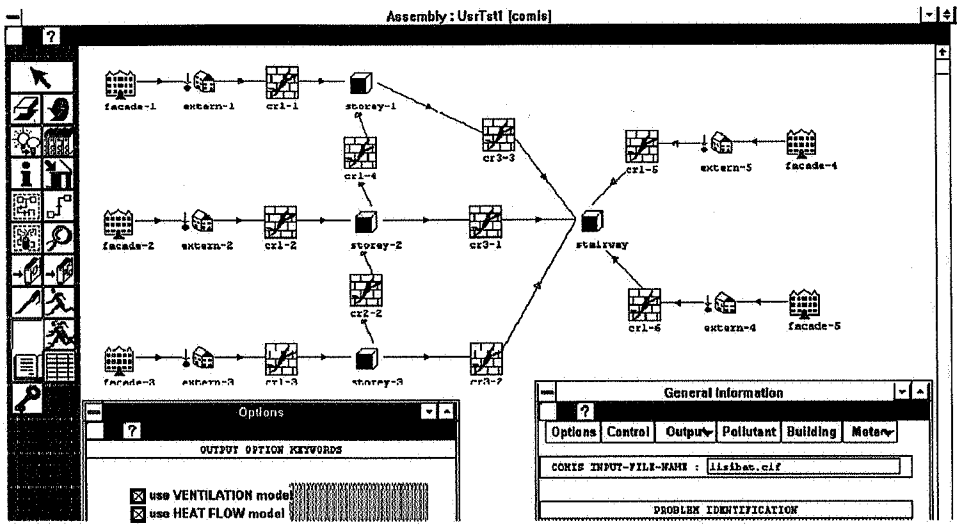
User Test 1

Numerical Reliability

A variety of tests were introduced to ensure that the program contained no numerical errors and would provide the same results irrespective of computer or operating system. This included 'User Test 1' which was developed as part of a joint contribution by the AIVC and LESO in Lausanne, Switzerland. This test represented a very simple network in which all openings and driving forces were defined and extreme parameters were set, aimed at establishing the ability of the algorithm to converge to a consistent solution under all possible conditions. This and other numerical tests, which compared results with known solutions, enabled inconsistencies and problems in the code to be quickly identified and rectified.

Evaluating Potential User Difficulties

A further test, 'User Test 2', was developed to evaluate the ability of the user to interpret input data and apply the data to a multi-zone model. Judgement was needed on the specification of items such as the number and



COMIS Sample Screen

location of flow paths, leakage coefficients, and wind pressure distribution. This approach pinpointed potential difficulties and highlighted further explanations that were needed in the COMIS User Guide. Results also showed that the ability of the user was critical in securing reliable predictions.

Comparing Numerical Predictions with Experimental Data

Ultimately the performance of a model can only be judged against its ability to compare favourably with reliably measured results. A comprehensive measurement programme and data sensitivity analysis was therefore undertaken. This included a mix of real buildings and test structures, with each being used to focus on a different aspect of multi-zone air flow. When compared against measurement data, numerical predictions were found to be generally of the correct magnitude, although there were sometimes significant differences in individual results. Much still depends on the interpretation placed on the input data by the user and there are clearly uncertainties over assigning wind pressure and air leakage data. Extensive testing has shown, however, that the algorithm itself is error free and accurately solves the basic flow equations.

Outcome and Conclusions

The main development of this annex has been the production of the COMIS model which is available in the public domain as a stand alone 'FORTRAN' Code. This has been thoroughly evaluated using a wide range of measurement data. Also available in the public domain is the Swiss interactive input algorithm, COMERL. Following further testing, the full Windows environment interface, IISIBat, will be available as a commercial product from CSTB in France.

Effort is still needed to improve the accuracy and transparency of input data. Nevertheless, provided the user is familiar with the implications of input data and has a good concept of the source and flow characteristics of openings and driving forces, the COMIS Model is capable of making a positive contribution to ventilation design and pollutant prediction.

For More Information

The current versions of COMIS and COMERL will be available by download from the Internet. Further details are available from the Operating Agent: Dr. Helmut Feustel, Lawrence Berkeley Laboratory, Building 90, Room 3074, Berkeley, CA 94720, USA, Phone +1 510 486 4021 Fax +1 510 486 6658 e-mail hefeustel@lbl.gov.

The Graphical User Interface IISIBat is available from Dr Roger Pelletret, CSTB, BP 209, 06 904 Sophia Antipolis, France: Tel +33 93 95 6700, Fax +33 93 95 6733, e-mail pelletret@cstb.

Price ffr 10,000 (reduced to ffr 6,000 to organisations in Annex 23 participating countries).

The COMIS User Guide and Fundamentals is available from the AIVC price £50.00 including postage and packing. The COMIS User Guide is also available 'free-of-charge' by 'ftp'. To obtain a copy, login using the following commands:

```
ftp epb1.lbl.gov
NAME:ftp
PASSWORD: (your email address)
FTP>cd package
FTP>binary
FTP>mget*
FTP>quit
```

This electronic version is a postscript file which can be printed out using your own printer.

Fully supported commercial versions of COMIS are also envisaged and details will be announced at a later date.

Annex 26 Air Flow in Large Enclosures

Background and Objectives

Large enclosed spaces are becoming a feature of modern architecture and are evolving in response to consumer expectations. Examples include shopping malls, atria buildings, airport terminals and covered sports stadia. Each presents enormous design problems in relation to heating and cooling loads, the provision of good air quality, and protection against smoke and fire movement. Without modern computational and measurement techniques, it is arguable that such buildings could not be constructed to an acceptable level of energy and environmental performance. Many spectacular buildings have now been designed and constructed on the basis of computational fluid dynamic analysis combined with physical scale modelling. However, as more designers wish to follow this route, it has become critical to ensure that these design techniques are correctly applied. A complete understanding of the implications of these methods is needed to avoid the risk of fundamental mistakes or to prevent too much reliance being placed on simulated predictions. Annex 26 was conceived to investigate the potential pitfalls and provide design guidance on the application of measurement and computational tools for understanding air flow patterns in large enclosures. The Operating Agent and Co-ordinater is Dr Alfred Moser of the Swiss Federal Institute of Technology, ETH, Zurich. Typical building sizes included in this study vary from approximately 1000 m^3 to over 100,000 m^3. These are essentially buildings in which thermal effects dominate and in which the occupied zones are small compared to the total enclosed volume.

The Tasks

Tasks included:

- developing design guidance and producing a design principles guide

- documenting and assessing analysis and prediction techniques
- documenting design case studies of existing large enclosures

The Design Principles Guide

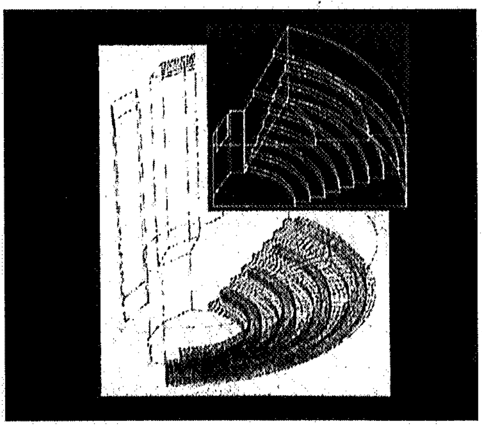
The design principles guide provides recommendations and advice for the planning of ventilation and air distribution systems in large enclosures. It focuses on information specific to the needs of such spaces, especially where this may differ from more conventional buildings. Particular aspects cover meeting ventilation, comfort, air quality and safety needs as well as energy implications, ventilation strategies, design techniques, applications, commissioning and feedback. Included in the Guide are worked examples, information on selecting ventilation rates, and advice on design parameters and strategy selection.

Analysis and Prediction Techniques

Measurement and calculation methods form a vital part of the design and evaluation process. Methods are evolving rapidly and some of the most up-to-date techniques (both elementary and complex), as currently used by researchers and specialists, are reviewed. The relevance of each approach within the context of the design, construction and evaluation process is considered. Design begins with 'macroscopic' methods based on engineering experience and simple analytical tools. As development continues, more sophisticated techniques are often necessary. Examples look at individual flow element models, zonal models (where the air space of a single room is subdivided into a relatively small number of zones or layers), computational fluid dynamics, physical (scale) models, ventilation efficiency evaluation and, ultimately, commissioning and evaluation measurements.

Case Studies

To support the analytical and design guide development, a total of twenty six case study buildings were monitored. Of these, seven reference case study buildings were selected for detailed measurements. These were two university auditoriums (De Montfort University, United Kingdom, 870 m^3, and Torino Polytechnic, Italy), an experimental 1/5th scale model atrium (Japan, 135 m^3), two sports halls (Norway, 128,340 m^3, and Germany, 2,230 m^3), a factory unit (France, 8,820 m^3) and a large atrium office building (Switzerland, 20 m high). Measurements included ventilation rates, air and surface temperature distribution, air velocity distribution and outdoor weather conditions (e.g. temperature and wind velocity). In most cases, thermal transfer, temperature and air flow velocity distributions were compared with various computational fluid dynamics and other modelling approaches.



CFD Design

Outcome and Results

The work of this team, both as Annex 26 and formerly Annex 20, has consistently produced simple guidance to assist in the reliable use of computational modelling and measurement techniques. This particular study has developed and perfected new methods and has provided new guidance on the operational needs and applicability of computational fluid dynamics models.

'Simple' analysis tools intended for basic engineering application include the 'flow element' technique in which the total flow field is predicted by analysing each element of flow, i.e. jets, plumes, boundary layer flow etc., individually. Similarly a simplified measurement procedure to evaluate building air leakage has been devised, aimed at identifying the position of the neutral pressure plane. This has been successfully applied to identify unexpected sources of air leakage in an enclosure.

At the more complex level, the performance of computational fluid dynamics models has been compared with measurement results. This has demonstrated the potential to predict flow and thermal patterns, to a reason-

Annex 26 Atrium Study

able degree of accuracy, especially as measured in the well instrumented Japanese test atrium. A zonal model, in which the space was discretised into control volumes, was also able to give a good prediction of thermal stratification. Important discoveries and conclusions concerning the use of computational fluid dynamics models include:

- Conventional computational fluid dynamics approaches incorporating k-ε type turbulence representation were found to be capable of giving reliable prediction results for temperature, air velocity and pollutant fields.
- Small changes to boundary conditions may significantly affect the main pattern of air flow and temperature distribution. It was therefore essential that boundary conditions were accurately represented. The extra effort expended to obtain realistic data is of proven value.
- Radiative heat transfer is a sensitive component of energy transport and must be incorporated in any computational fluid dynamics analysis.
- Convective heat transfer from boundaries to the air were not reliably predicted using coarse grid systems and log law wall functions. Results tended to be grid spacing dependent. The use of prescribed convective heat transfer coefficients were proposed instead, although it was acknowledged that this might not always be easy. New wall functions for free-convection heat transfer are now being developed by Annex 26 participants, and the application of these functions are presently being tried out.
- Slow or non-existant convergence of the solution procedure was found in some instances. This tends to occur when flow is dominated by free convection forces (i.e. thermal buoyancy). It was demonstrated that this problem could be overcome by using a 'coupled' rather than a conventional 'sequential' (SIMPLE) solver. In addition, instability in solutions was found in an isothermal calculation of the air jets in the sports hall in Germany. It is believed that the physical flow exhibits low-frequency oscillations. It is concluded that such flows may only be modelled by time-dependent computation. A steady-state model will never converge.

For More Information

The final Annex 26 report is entitled:

"Ventilation of Large Spaces in Buildings", and will have three main parts as follows:

1) "Design Guide", edited by Robert J. Waters.
2) "Case Studies", edited by Dirk Mueller and Norbert Vogl
3) "Analysis and Prediction Techniques", edited by Per K. Heiselberg.

Details of availability of the final report will be published in this newsletter, and information may be obtained from the Operating Agent on <moser@iet.mavt.ethz.ch>.

Acknowledgements

Much of the information presented in this review was based on reports and assistance provided by the Operating Agent of Annex 23 - Dr. Helmut Feustel of the Building and Environment Division of the Lawrence Berkeley Laboratory, California, and the Operating Agent of Annex 26 - Dr. Alfred Moser of the Swiss Federal Institute of Technology , ETH, Zurich.

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