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15th AIVC Conference

The Role of Ventilation

27th - 30th September 1994, Palace Hotel, Buxton, UK

By Malcolm Orme, AIVC Scientist

The 15th AIVC Annual Conference was recently held in the English Georgian Spa town of Buxton which is situated in the heart of the Peak District. The three day conference was supported by over one hundred delegates from fourteen different countries, who had the opportunity to attend a full programme of poster and paper presentations.

Keynote Address

The Keynote Address was given by Dr David Fisk, Chief Scientist at the UK's Department of the Environment, who outlined the role of ventilation in providing an optimum indoor environment which must be balanced with energy efficiency considerations. Quoting from the recent report on the work of the AIVC by the IEA Energy End Use Working Party, Dr Fisk said, "*The Centre could be said to have brought about enormous energy savings...,it may even have delivered the highest cost/benefit or the greatest energy savings accountable to any one single IEA research activity*". He went on to emphasise, that those working in the field are helping to resolve the conflict between ventilation requirements and energy use, and that lowering carbon dioxide emissions is a natural consequence of reducing wasted energy, as well as conserving vital energy reserves.

Introductory Session on Ventilation Strategies

Richard Walker (BRE, UK) opened the first session with a discussion on a homogeneous emission tracer gas technique, which has been developed specifically for measuring ventilation rates in large, multi-zone buildings. The method was tested on a selection of different office building types. A simplified version of the technique has also been devised, using commercially available test equipment, in order

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to make it easier to apply. From Belgium came a presentation which dealt with determining ventilation rates of an outdoor test cell with a single large opening by means of a tracer gas method and also by using the measured heat balance of the cell. David Ducarme (BBRI, Belgium) reported that the heat balance approach was found to be most accurate, as the air in the cell was not sufficiently mixed to allow the tracer gas to become homogeneously dispersed.

Research on Passive Stack Ventilation

Additionally, in the first session, Mark Bassett (BRANZ, New Zealand) explained about his theoretical studies concerning passive window ventilators and passive stack ventilation (PSV), in comparison with experimental work concentrating on passive window ventilators. The experimental results appeared to support a simple linear relationship between added ventilator area and added ventilation rate, as had been determined by the theoretical analysis. PSV in 4 occupied dwellings was described by Lynn Parkins (BRE, UK). From this she inferred that there is a need for clear and simple guidance on such systems to enable them to work at maximum efficiency. In a separate poster, she explained how these systems performed when installed in a test house. PSV in the residential sector was a subject explored by several other speakers during the Conference.

Later in the week, Chris Irwin (Aereco Ventilation, UK) indicated how an assessment of performance data from apartments in France, Belgium, and The Netherlands leads to the conclusion that PSV can also be used successfully in UK apartment blocks. On behalf of some colleagues, Jorma Sateri (VTT Building Technology, Finland) gave an account of a project designed to evaluate ventilaton heat loss by simulation in both PSV and mechanical systems. The results seemed to suggest that air flow rates in PSV systems are too high in winter and too low in summer, but the situation could be improved by means of controlled air inlets and outlets. (The same poster showed that mechanical extraction systems can be improved with demand-control instead of time control.)

Mark Bassett (BRANZ) explains details of PSV at poster session

Another example of the evaluation of this technique was undertaken by Mike Woolliscroft (BRE, UK), in which he estimated the annual ventilation energy used by PSV (both uncontrolled and humidity controlled) and that used with humidity controlled extract fans in identical buildings. A description of the improvements made to a test house was given by Sarah Palin (EA Technology, UK). It now includes mechanical ventilation with heat recovery, PSV and extract fans, enabling the different systems to be compared in the same building. In addition to the above, a paper from France, and 2 posters from the UK also dealt with PSV.

The Significance of Occupant Behaviour

It has emerged that the behaviour of occupants becomes increasingly significant as more emphasis is placed on correctly ventilating buildings. The work of IEA ECBCS Annex 27 was described by its Operating Agent, Lars-Göran Månsson (LGM

Air
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Review

Editor: Janet Blacknell

Air Infiltration Review has a quarterly circulation of 3,500 copies and is currently distributed to organisations in 40 countries. Short articles or correspondence of a general technical nature related to the subject of air infiltration and ventilation are welcome for possible inclusion in AIR. Articles intended for publication must be written in English and should not exceed 1,500 words in length. If you wish to contribute to AIR, please contact the Air Infiltration and Ventilation Centre. Please note that all submitted papers should use SI units.

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.

Consult AB, Sweden) in his paper "Occupant Habits' Influence on Ventilation Need", which summarised the activities of this Annex, and focused on the background information they had gathered in order to carry out their work.

On a similar subject, Niels Bergsoe (DBRI, Denmark) analysed the results of a survey of the occupants of 150 naturally ventilated single family houses in Denmark, where detailed ventilation rate measurements had been taken. He remarked that, even when the ventilation rates were found to be low, the majority of occupants were satisfied with their perceived quality of indoor air. A Case Study of occupant behaviour in relation to indoor air quality was also carried out in two French schools by Veronique Richalet (ENTPE, France).

Measurement Techniques

A system has been developed for tracking air movement in buildings, which was talked about by Don Alexander (UWCC, UK). Digital image processing converts video recordings of the motion of neutral density balloons or bubbles into 3-D positions and velocities, as air displaces them. Balloons were found to be suitable for use in occupied structures and can be used in large spaces. On the other hand, bubbles were determined to be better suited for studying flow near or within air jets.

Amongst the many posters displayed at the various sessions was Hannes Müller's (Technische Universität Dresden, Germany) which considered the advantages and limitations of thermography, the usage of thermocouples, and hot wire anemometry, especially for supplying appropriate boundary conditions for use in numerical computations. Figure 1(a) shows a picture of a room obtained from infrared thermography, whilst Figure 1(b) is a representation of the temperature profile of one of its walls, after processing.

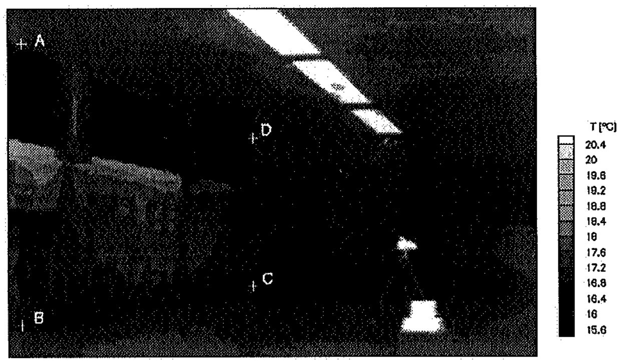

Figure 1(a) Original infrared picture with corner points A,B, C and D for rectification

Minimising Energy Use in Large Scale Systems

How mechanical ventilation systems can be optimised to use the least energy, with particular reference to large scale (commercial sector) systems was discussed by Fritz Steimle (Universität GHS Essen, Germany). He concluded that the most effective methods are to (a) make ducts sufficiently large; (b) control pollutant emissions at source; and, (c) make efficient use of fans by controlling shaft speed in order to vary the volume flow rate of air.

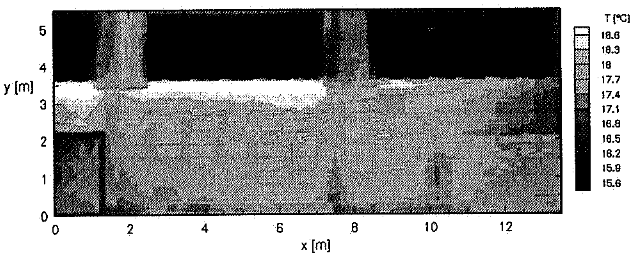

Figure 1(b) Picture obtained after rectification and ε-correction from Figure 1(a)

Prevention and Dispersal of Excess Pollutants

A number of the papers and posters presented at the Conference were concerned with the prevention and dispersal of excess pollutants from the indoor environment. These included 3 posters from the UK on the subject of controlling radon levels in dwellings, as well as one from Finland dealing with radon in underground workplaces. The problem of reducing high humidity levels in dwellings was examined by both Tom Shepherd (BRE, UK), who compared different strategies for decreasing the air humidity in a kitchen, and Mats Sandberg (Royal Institute of Technology, Sweden), whose paper related details of laboratory experiments to determine how to ventilate bathrooms in the most energy efficient manner. Also, indoor plants, as possible sources of airborne moisture, were looked at by Beat Strickler (ETH, Switzerland) to ascertain how they affect indoor humidity levels under known climatic conditions. Maria Kolokotroni (BRE, UK) talked about how to mitigate passive smoking in houses, and suggested various courses of action for use both in and out of the heating season.

New Tools and Source Data for Modelling and Design

An overview of the multi-zone airflow and contaminant dispersal model CONTAM93, including an example application, was demonstrated by Steve Emmerich (NIST, USA). Jean-Marie Furbringer (LESO-EPFL, Switzerland) stressed the importance of being aware of the uncertainties associated with input data for numerical modelling, and in fact highlighted results from several models to indicate how these uncertainties can influence the outcome. The AIVC's Numerical Database (recently reported in the September edition of "AIR" and currently available from the Centre) was demonstrated by Malcolm Orme (AIVC, UK) who described the various types of airtightness data to be found in the database.

Lawrence Berkeley Laboratory have collated information, from several different sources, on airtightness measurements taken from 12500 US dwellings. Max Sherman (LBL, USA) stated that, although this dataset did not claim to be representative of the whole US building stock, it did seem to indicate that dwellings there are leakier than had been previously estimated.

Steve Sharples (University of Sheffield, UK) revealed some research into fluctuating air flow through cracks by experiments and computational fluid dynamics (CFD) simulation. He also conducted a laboratory investigation into the airtightness characteristics of ideal cracks, with varying degrees of internal surface roughness.

A means of testing and rating ventilation duct terminals was described by Paul Welsh (BRE, UK) whilst Li Shao (University of Nottingham, UK) continued this topic with a poster on the determination of pressure loss factors for ducts by means of measurements and CFD modelling.

Going Against the Flow

Dynamic insulation is a method of construction by which air is forced through the insulation, usually from the colder outside air, into the heated building. On the basis of field experiments, Jørn Brunsell (NBI, Norway) arrived at the conclusion that by using this method it is possible to ventilate without draughts, and to virtually eliminate heat loss from the construction.

Finally, Hans Phaff (TNO, The Netherlands) discussed a technique for the control of air flow directions between the zones in buildings. The Air Lock Floor and Pressure Ring are innovative applications of this technique, which relies on the creation of a pressure hierarchy in order to function. Figure 2 shows a representation of the operation of the Air Lock Floor. This can be used to prevent air flowing from a crawl space to the living space above it.

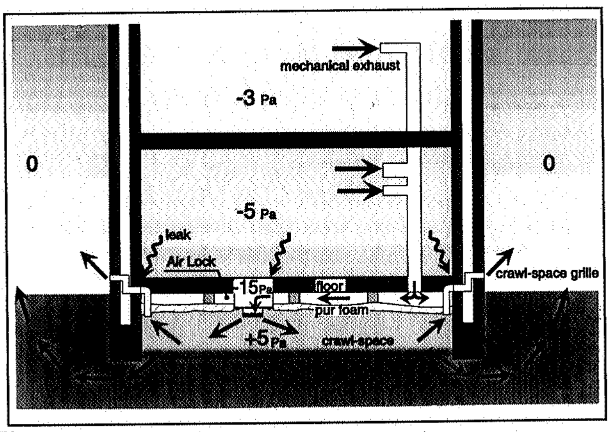

Figure 2 The Air Lock Floor (ALF) in a dwelling

Best Paper and Best Poster Awards

Delegates were invited to vote for their choice of "Best Written Paper" and "Best Poster Display". In a close run contest the worthy winners proved to be Iain Walker (NRC, Canada) for his paper, "Practical Methods for Improving Estimates of Natural Ventilation Rates" (co-authored with David Wilson) and Frank Scholzen (ETH, Switzerland) for his poster entitled, "Particle-Streak-Velocimetry for Room Air Flows" (co-authored with Alfred Moser and Peter Suter). Iain Walker's paper demonstrated a method of taking upwind obstructions into account in order to modify surface wind pressure coefficients, including the effect of wind direction. Frank Scholzen, demonstrated that by using the measurement technique portrayed in his poster, a quantitative visualisation of room air flows can be performed by digitally analysing the images recorded simultaneously at 3 different camera positions. (A streak photograph of discrete particles is taken from each location.) Figure 3 shows a cross-section through the velocity field derived in one such case. The awards were presented at the Conference Dinner by a most entertaining Guest Speaker, Ian Macpherson.

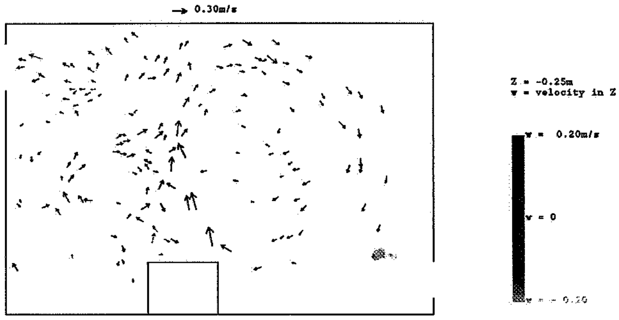

Figure 3 Velocity vectors extracted out of three camera view points

Summing Up

The proceedings were brought to a close by a joint summing up partnership of Viktor Dorer (EMPA, Switzerland) and Willem de Gids (TNO, The Netherlands) who between them gave a synopsis of the principle themes which had emerged from the previous 3 days of presentations. They emphasised the following areas:

- Energy
- Modelling
- Design
- Strategies
- Indoor air quality
- Measurements

The AIVC would like to thank all those who attended, as well as those who presented material at this year's Conference.

The Proceedings of the 15th Conference are published by the AIVC in two volumes, price £50.00 Sterling. (Please see the Order Form at the back of this newsletter.)

International Energy Agency

Air Infiltration and Ventilation Centre

16th Annual Conference

Implementing the Results of Ventilation Research

Palm Springs, California, USA

Tuesday 19th - Friday 22nd September 1995

First Announcement and Call for Papers

Considerable effort has been devoted to research into ventilation technology and its impact on indoor air quality and energy demand. The purpose of the AIVC's 16th annual conference is to review the implementation of the results of recent research. Abstracts of papers on the following topics are particularly invited.

- ***Energy efficient ventilation strategies***

Ventilation methods have changed over the last 15 years from reliance on air infiltration and window opening to controlled mechanical and natural techniques. The requirements covering ventilation of dwellings and commercial buildings have also developed substantially in almost all IEA countries. Modern systems can be much more responsive to occupant needs, resulting in improved indoor air quality and substantial gains in energy efficiency. Intended papers should cover the application of new techniques and the results of field studies.

- ***Ventilation heat recovery***

Heat recovery systems may be used to advantage with almost all ventilation systems. Developments have progressed from air to air systems to heat pumps and controlled air flow through 'dynamic' insulation. Examples illustrating the performance and application of heat recovery systems are invited.

- ***Maintenance and long - term performance***

Reliability and ease of maintenance are key factors in ensuring the take up of complex systems. Papers are needed that cover these aspects in relation to problems, the development of Codes of Practice and designing for minimum maintenance.

- ***Controls and user interaction***

The interface between the system and the occupant has a significant impact on ventilation performance. Examples should cover user friendly controls and the needs of occupants.

- ***The application of mathematical models in design***

Modelling techniques have also developed considerably, with current models varying from simple evaluation tools to total building energy and air quality evaluation methods. Papers describing the demonstration and use of all types of models are welcome.

- ***Measurements for design and diagnostic analysis***

Measurement systems designed for research have given way to more user friendly products that can be applied by the less well skilled. It is proposed to cover examples illustrating the development and application of modern measurement methods.

Abstracts of approximately 300 - 500 words are invited on the above or related topics. These should be sent to Rhona Vickers at the Air Infiltration and Ventilation Centre, (details on back page).

CONTAM93 A Multizone Airflow and Contaminant Dispersal Model with a Graphic User Interface

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Abstract

A new multizone airflow and contaminant dispersal program CONTAM93 is described. While this program is based on existing theory of network airflow analysis and contaminant dispersal, it employs a unique graphic interface for data input and display. The interface uses a sketchpad to describe the connections between zones and icons to represent zones, openings, ventilation system components, and contaminant sources and sinks. The program, its graphic interface and plans for its further development are described.

Introduction

Airflow rates in buildings are determined by the interaction of the building structure, its HVAC system, and weather conditions. Indoor pollutant concentrations depend on these airflow rates, pollutant source and sink characteristics, and outdoor concentrations. A whole-building, multizone approach, accounting for all of these factors, is required to study many important issues in building airflow and IAQ and has been implemented in many multizone airflow and IAQ models. A survey of multizone models, all of which provide at least some of the required modeling capabilities, is described by Feustel and Dieris (1). This paper describes a new multizone airflow and pollutant transport program CONTAM93 (2), which is the latest in the series of multizone IAQ modeling programs developed at the National Institute of Standards and Technology (NIST). The application of CONTAM93 in a residential IAQ modeling study was discussed at the 15th AIVC Conference (3).

CONTAM93 - General Description

CONTAM93 is an easily used contaminant analysis program combining the best available algorithms for modeling the airflow and contaminant dispersal in multizone buildings. It employs a graphic interface and is usable on commonly available small computers. Over the past several years, NIST has developed a series of public domain computer programs for calculating airflow and contaminant dispersal in multizone buildings. The earliest such program was ASCOS (Analysis of Smoke Control Systems) (4). Another program, TARP (Thermal Analysis Research Program) (5, 6), used multizone airflow calculations to estimate the portion of building thermal load due to infiltration and perform a simple contaminant migration analysis. Programs developed specifically for the study of contaminant dispersal included CONTAM86 (7) and CONTAM87 (8). NBSAVIS/CONTAM88 (9) added multizone airflow analysis capability, based on the program AIRMOV (10), and a menu-driven interface to CONTAM87. Improvements in the airflow calculation algorithm were implemented in the AIRNET program (11). CONTAM93 combines a new graphic interface with the contaminant simulation capabilities of CONTAM88 and the airflow analysis method of AIRNET.

CONTAM93 requires a 286-class (or higher) PC compatible computer with math coprocessor, VGA graphics, and MS-DOS. CONTAM93 consists of two programs: CONTAM and CONTAMX. CONTAMX is a non-interactive program which computes the airflows and/or contaminant concentrations in a building from information on the building, its HVAC system, ambient conditions, contaminant sources, and contaminant removal mechanisms. CONTAMX can perform steady-state, transient (up to 24 hour), and 24-hour cyclic simulations with a user specified time step. CONTAM is an interactive program for processing the required CONTAMX input and for displaying or exporting the CONTAMX output. Both CONTAM and CONTAMX operate under the 640K-byte memory limit of MS-DOS, which is sufficient for simulating buildings with several hundred zones and multiple contaminants.

Graphic Interface

When using CONTAM93, the user does not directly access the data files describing the building. All access to the building description is done through the CONTAM program and its graphic interface. The description of the building is created (or modified) in the SketchPad. The SketchPad consists of an invisible array of about 3600 small cells into which the user places various symbols representing building features relevant to the calculation of airflow and contaminant dispersal. This produces a simple illustration which has been chosen intentionally to represent the simplicity of the underlying mathematical model. The SketchPad is used to establish the geometric relationships of the relevant building features. It is not intended to produce a scale drawing of the building. Instead, it is used to create a simplified model where the walls, zones, and airflow paths are topologically similar to the actual building. The SketchPad allows the entry and display of the data in an intuitive manner. The SketchPad brings up various data entry screens needed to define the mathematical characteristics of the various building features (e.g. leakage areas and contaminant source strengths). After performing the simulation, the flows and pressure drops at each opening are presented on the SketchPad. Transient contaminant concentrations can also be displayed as separate graphs.

The CONTAM93 SketchPad is designed to simplify the data input and analysis processes for a multi-zone airflow and contaminant dispersal simulation. It is still up to the user to decide how best to idealize the building as a multizone system based on the building layout and the objectives of the simulation. The user must also determine which contaminant dispersal processes are important and appropriate input values for the building being simulated. The required input values can be numerous and include the following: airtightness of exterior envelope and interior partition components, ventilation system airflow rates, wind pressure coefficients, ambient weather and contaminant concentrations, indoor contaminant source strengths and sink characteristics, contaminant reaction rates, and filter efficiencies. Values of these quantities can be determined from the published literature and field measurement.

Once the user has decided how to represent the building as a multizone system and has determined appropriate input values, the building data is entered into the SketchPad. Building data is organized by levels with data entry beginning at the lowest level. A level would typically be a building floor, but a suspended ceiling acting as a return air plenum or a raised floor acting as a supply plenum may also be treated as a level leading to multiple levels per floor. Each level is divided by walls into separate regions of uniform air temperature, pressure, and contaminant concentration called zones. Walls include the building envelope and internal partitions with a significant resistance to air flow, and are drawn as either horizontal or vertical lines. There is a set of implicit walls (generally floors) separating the zones on different levels. A default ambient zone surrounds the building. Other zones can be designated as ambient to represent, for example, a courtyard. An airflow path indicates some building feature by which air can move from one zone to another. Such features include cracks in the building envelope, open doorways, and exhaust fans. Path symbols placed on the walls are used to represent openings between zones or to ambient; any other placement represents an opening in the floor to the zone on the level below. Contaminant source (or sink) symbols may be placed in any zone. These represent any feature (within the list of available models) which produces or removes a contaminant. A simple model of an air handling system is available with supply and return point symbols placed within the appropriate zones. All supply and return airflows follow user defined schedules.

Figure 1 shows the floor plan of a ranch style house and Figure 2 shows the CONTAM93 SketchPad representation of this house. In this case the representation closely mimics the floor plan. Airflow paths are represented by the diamond-shaped symbols on the walls. The zone symbols are squares with x's inside; the contaminant sources are boxes with c's inside. The air handling system, system supply points, and system return points are represented by a bold S, squares with +'s inside, and squares with -'s inside, respectively.

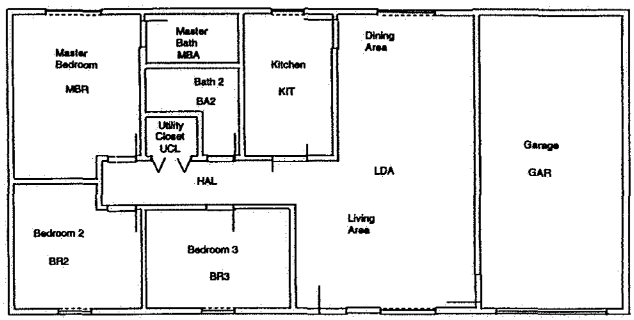

Figure 1 - Miami ranch house floorplan

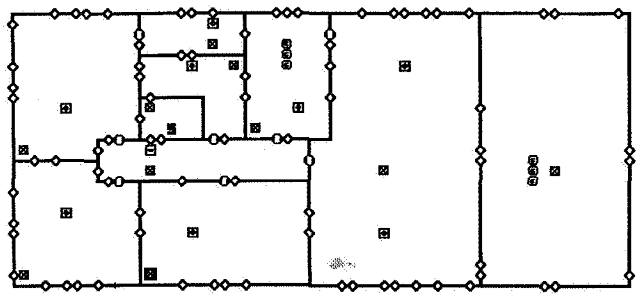

Figure 2 - Miami ranch house in CONTAM93 SketchPad

Future Development Plans

Work is presently in progress to improve the user interface and to extend the simulation capabilities. The logic of the interface is being made more similar to common graphic interface standards, although the next version of the program will still run under DOS. The program is being modified to include libraries of airflow paths and contaminant source/sink models. Extensions in the simulation capabilities will include detailed ductwork models, exposure analysis, non-linear contaminant chemistry, and aerosol transport.

An interim version of the program, called CONTAM94, with an improved interface and employing a DOS extender has been completed. CONTAM94 is a beta-test program with a revised graphical user interface that is serving to test the next generation of the program - CONTAM95. A DOS extender has been used to allow merging of the I/O processor and the simulation programs into a single program. Because of the extender, CONTAM94 requires a 386 class (or higher) PC compatible computer with math coprocessor (preferably 486DX), VGA graphics, and MS-DOS. The higher CPU is also used by the 32-bit code generated by the compiler, making CONTAM94 slightly faster than CONTAM93.

CONTAM94 includes the following positive (+) and not-so-positive (-) features:

+ The interface has been revised to more closely follow GUI conventions. This makes it much easier and faster to switch between the various screens. Some icons have been modified for better visibility or compatibility with common practice.

- Simulation capabilities are essentially unchanged from CONTAM93.

- Documentation has not yet been revised, but the on-screen help has been updated. Pressing F1 gives information about what the program is requesting from the user, e.g., the physical description of a flow element and its input parameters. F2 gives information about how to perform the current operation, e.g., how to enter an element name or copy an icon.

+ It combines the I/O interface and the simulator into a single program. This gives a very fast response for steady-state problems.

+ This DOS extender allows creation of projects up to the size of available memory. This allows simulations of up to 8000 (zones x contaminants), effectively removing limits on the complexity of the problem.

- Unfortunately, it also appears to conflict with Windows -- stay in DOS at boot-up.

+ It allows the creation of a scrollable SketchPad which is larger than the screen (up to about 32,600 cells). This is very useful for large, low-rise buildings.

+ Multiple projects may be run without exiting the program. The name of the current project is always displayed.

+ An entire level may be deleted; a new level may be added above or below any existing level.

- Note that CONTAM94 cannot use CONTAM93 project files directly.

+ They must be converted to a revised format using the C93TOC94 utility: C93TOC94 .prj .prj

Comments on CONTAM94, as well as CONTAM93, would be greatly appreciated.

Availability

CONTAM93 and 94 are most quickly available via FTP on the Internet accessing NIST's VAX external network host. Use the following procedure:

ftp enh.nist.gov	FTP - Internet address
user name: anon	signon
password:	enter your Internet address
cd contam	change to CONTAM directory
bin	set binary transfer mode
get <file>	get file
...	get other files
bye	signoff

Get the CONTAM93.TXT and CONTAM94.TXT files first. These short files describe the other files that are available for CONTAM93 and/or CONTAM94. Intermediate fixes to the programs will be posted here as they are developed. These fixes will be reported in the .TXT files. Please e-mail a note to gwalton@enh.nist.gov when you use FTP to get a CONTAM upgrade so your name can be added to the CONTAM mailing list.

If you do not have access to FTP and the Internet, call or write for a disk. Contact: George Walton, BR/A313 NIST, Gaithersburg MD 20899, U.S.A.; phone: (301) 975-6421; fax: 990-4192.

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Award Winning Paper from the 15th AIVC Annual Conference

Practical Methods for Improving Estimates of Natural Ventilation Rates

by Iain Walker and David Wilson,
Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada

Synopsis

This paper discusses four concepts that have been found useful in improving estimates of ventilation rates in residential buildings. These concepts are improved methods for describing leakage distribution and wind pressures:

1. Separation of large, well defined "local" leakage sites from the background building leakage.

2. Changing surface pressure coefficients to account for the effect of upwind obstacles.

3. Making wind pressures (in terms of pressure coefficient and wind shelter) continuous functions of wind direction.

4. Development of a wind shadow shelter model specifically tailored for buildings in urban locations.

The effectiveness of the implementation of these four concepts was examined by comparing predicted ventilation rates using a computer model (LOCALEAKS) that incorporates these concepts to several thousand hours of ventilation measurements from the Alberta Home Heating Research Facility (AHHRF). The houses at AHHRF have been tested in several leakage configurations to evaluate the model performance over a wide range of parameters. For brevity, a single leakage configuration is discussed in this paper that shows the success and failures of the model in predicting ventilation rates for complex leakage and shelter configurations. The above methods for improving ventilation calculations can be applied to other models and are not restricted to use in the ventilation model used for this study.

1 LOCALEAKS Ventilation Model

This ventilation model was specifically developed to incorporate the methods for improving ventilation rate estimates outlined above. LOCALEAKS balances the flow in and out through the building leaks by applying the power law pressure flow relationship, given below, to each leakage site.

$$M = \rho C(\Delta P)^n \qquad (1)$$

where M is the mass flow rate [Kg/s], C is the flow coefficient [m^3/sPa^n], n is the leakage exponent, ρ is the air density [Kg/m^3] and ΔP is the pressure difference [Pa] across the leak. The flow coefficient is split into distributed and localised leakage, and the pressure difference is due to a combination of stack and wind effects, and the pressure that acts to balance the inflow and outflow.

1.1 Pressure Differences for Flow through House Leaks:

The total pressure difference across each leak can be written in terms of a reference wind parameter, P_U, and stack effect parameter, P_T, common to all leaks:

$$P_U = \rho_{out}\frac{U_H^2}{2} \qquad (2)$$

$$P_T = g\rho_{out}\left(\frac{(T_{in} - T_{out})}{T_{in}}\right) \qquad (3)$$

where ρ_{out} is the outdoor air density, U_H is the eaves height wind speed [m/s], g is the gravitational constant (9.81 m/s^2), T_{in} is the indoor temperature [K] and T_{out} the outdoor temperature [K]. The total pressure difference is due to a combination of the wind and indoor-outdoor temperature difference effects and the pressure that acts to balance the inflows and outflows ΔP_I.

$$\Delta P = CpS_U^2P_U - ZP_T + \Delta P_I \qquad (4)$$

Equation 4 is applied to every leak for the building with the appropriate values of pressure coefficient (Cp) wind shelter factor (S_U) and Z (the height above grade). Thus, each leak is defined by its height, shelter and pressure coefficient.

2 Leakage Site Separation

2.1 Distributed Leakage

The unintentional "background" leakage through cracks and holes is distributed in six separate locations: ceiling, floor, and each of the four walls. The flow coefficient C_{dist} for the distributed leakage and exponent n_{dist} are found from a fan pressurization test, or estimated from similar construction types. The same value of n_{dist} is used for all sites, and the flow coefficient is given by

Equation 5, with wall, ceiling and floor level leaks specified as a fraction of the total.

$$C_{dist} = C_{ceiling} + C_{floor} + C_{wall1}$$

$$+ C_{wall2} + C_{wall3} + C_{wall4} \qquad (5)$$

2.2 Local Leakage Sites

Local leakage sites may be at floor level, in the ceiling, and in the walls. The default assumption for these sites is that they act like sharp edged orifice holes with n_{local} - 0.5 and an effective flow area of C_dA_{local}, where C_d (typically 0.6) is the discharge coefficient and A local is the flow area of an opening. Alternately, the flow coefficient C_{local} and n_{local} may be specified for each local leakage site. For wind pressures each local leak is given the same pressure coefficient and wind shelter as the surface it is located in. LOCALEAKS uses a single averaged wind pressure coefficient for each wall of the building, so that only the height above grade of each local leakage site needs to be specified, rather than its horizontal location on a wall.

3 Changing Pressure Coefficients to Account for Upwind Obstacles

The wind pressure coefficients, Cp, are taken from wind tunnel tests. It is assumed that there is no specific horizontal location for a leak on a wall and so extremes of pressure coefficients occurring at corner flow separations, for example, are not included. This assumption allows the simplification of using wall averaged pressure coefficients.

A set of comprehensive wind tunnel tests that cover many different wind directions have been presented by Akins, Peterka and Cermak [1]. Their Cp's are representative of isolated houses but it has been found in the development of LOCALEAKS that a change of side wall Cp is necessary for houses in a row. For an isolated building the side wall is about Cp -0.65 based on Akins, Peterka and Cermak's measurements. For houses in a row with the wind along the row, the upwind houses change the flow pattern around the building so that large flow separations do not occur on the sidewalls. This requires a reduction in magnitude of the side wall pressure coefficient to about Cp = -0.2. This value was found by Wiren [2] in tests of row house shelter and is suggested by model errors in passive ventilation studies performed by Wilson and Walker [3]. Analysis of Wiren's data by Walker [4] has shown that for a house to be considered to be in a row only one upwind house is necessary because the closest obstacle dominates the wind flow pattern. The wind pressure coefficients for the other walls are taken directly from Akins, Peterka and Cermak. For wind perpendicular to the upwind wall they are: Cp = 0.6 for the upwind wall and Cp = -0.3 for the downwind wall.

4 Making Pressure Coefficients a Continuous Function of Wind Direction

When the wind is not normal to the upwind wall the above pressure coefficients do not apply. An harmonic trigonometric function was developed to interpolate between these normal values to fit the variation shown by Akins, Peterka and Cermak and Wiren. For each wall of the building the harmonic function for Cp was empirically developed in the following form:

$$Cp(\theta) = \tfrac{1}{2}\,[(Cp(1)+Cp(2))(\cos^2\theta)^{1/4}$$

$$+ (Cp(1)-Cp(2))(\cos\theta)^{3/4}$$

$$+(Cp(3)+Cp(4))(\sin^2\theta)^2+(Cp(3)-Cp(4))\sin\theta] \qquad (6)$$

Where Cp(1) is the Cp when the wind is at 0 (+0.60)

Cp(2) is the Cp when the wind is at 180 (-0.3)

Cp(3) is the Cp when the wind is at 90 (-0.65 or -0.2)

Cp(4) is the Cp when the wind is at 270 (-0.65 or -0.2)

and θ is the wind angle measured clockwise from the normal to the wall.

This function is shown in Figure 1 together with data from Akins et al for a cube. The error bars on the data points in Figure 1 represent the uncertainty in reading the measured values from the figures of Akins, Peterka and Cermak. Equation 6 fits the measured data within about Cp = ± 0.02 except at about 150 degrees and 210 degrees (which are the same by symmetry) where the equation overpredicts the Cp by about 0.1. Figure 2 shows Equation 6 with Cp's from another data set from ASHRAE [5] (Chapter 14) which it also fits well.

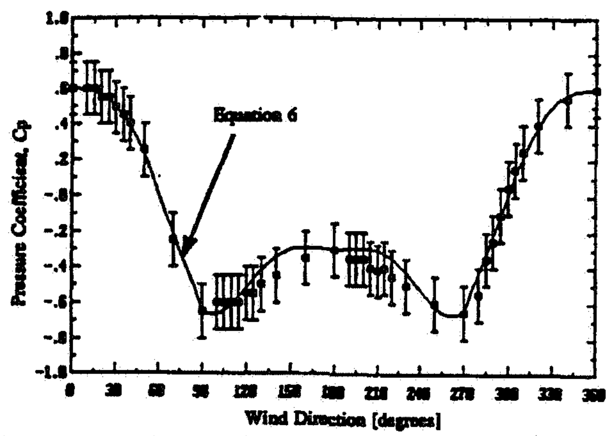

Figure 1 Wind angle dependence of measured (data from Akins et al (1979)) and predicted wall pressure coefficients for isolated buildings.

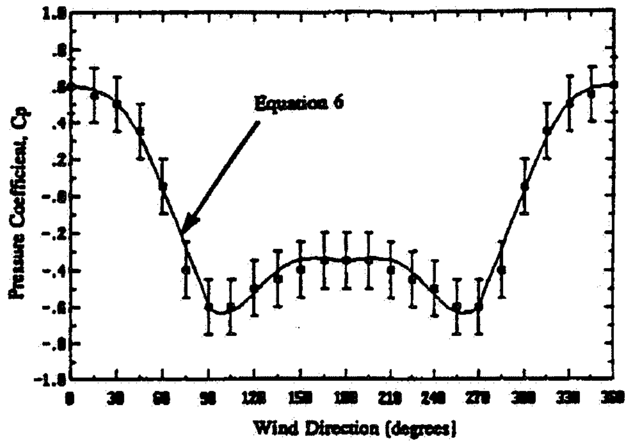

Figure 2: Wind angle dependence of measured (data from ASHRAE (1989)) and predicted wall pressure coefficients for isolated buildings.

The function in Equation 6 was chosen to have the above form so that if a different data set were to be fitted then only the values for when the wind is normal to one wall are required and function will estimate the intermediate values for different wind directions. Equation 6 is shown in Figure 3 for the row pressure coefficients where the sidewall Cp is -0.2. There are no intermediate measured values but this figure shows that Equation 6 produces reasonable pressure coefficients for this case. The value for pressure coefficient at the top of the furnace flue is Cp=-0.5, based on measurements by Haysom and Swinton [6].

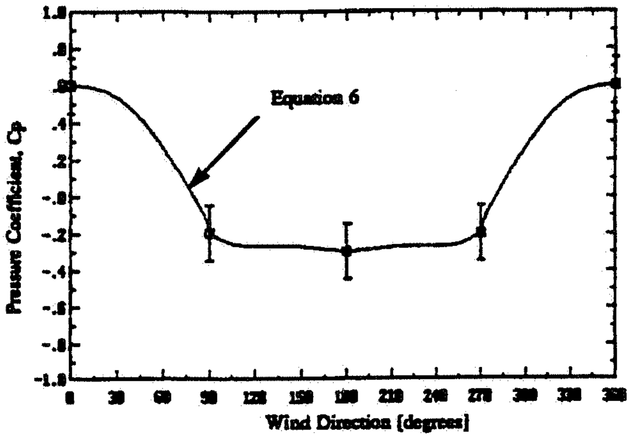

Figure 3: Wind angle dependence of wall pressure coefficients for houses in a row.

5 Wind Shadow Shelter

To improve shelter estimates the wind shelter method was developed to calculate numerical values for the reduction in velocity caused by an upwind obstacle. The shelter method is based on work by Walker and Wilson [7]. The shelter factor, S_U, is used to reduce the eave height wind speed, U_H, in the flow approaching the building to produce an effective wind speed U, such that

$$U = S_U U_H \qquad (7)$$

U calculated from Equation 7 is used to calculate the wind pressure on each wall in Equation 4. When the walls are not sheltered, S^U = 1.0 and complete shelter corresponds to S_U = 0. Wind shadow wake shelter uses self-preserving three dimensional wake theories of Counihan, Hunt and Jackson [8] and Lemberg [9] to determine the rate of recovery of wind speed in the wake of an upwind obstacle. The theories are combined with wind tunnel measurements of Peterka, Meroney and Kothari [10], Lemberg [9] and Wiren [2] to develop appropriate relationships for wind shelter factor (or windspeed multiplier), S_U, to be used in the near wakes of interest in building shelter problems.

The wind shadow concept is analogous to the shadow produced by an obstacle in front of a light source that is cast onto another surface. The projection of the wake downstream of the sheltering obstacle is the "wind shadow". If a surface is partially covered by the wind shadow of the projected wake, then the shelter factor is weighted by the amount of wall area covered by the wind shadow to obtain the average shelter factor for the wall.

For this study, a computer programme was used to calculate S_U for all four walls of the test buildings at AHHRF every one degree of wind angle. The houses are in a east-west row, and are exposed for north and south winds and shelter each other for east and west winds. The calculated values of S_U are illustrated in Figures 4 and 5. Figure 4 is for the North facing wall and shows the symmetry of its shelter with a maximum wind speed reduction factor of S_U = 0.43 for winds from 110 and 250 degrees. Figure 5 is for the east facing wall where the shelter is asymmetric because the sheltering building is closer for east winds than west winds. For east winds (90 degrees) the shelter is maximum with S_U = 0.25. For west winds the shelter is less with S_U = 0.61. The furnace flue protrudes above the houses and is assumed to be unsheltered, and S_U = 1.0 for the flue.

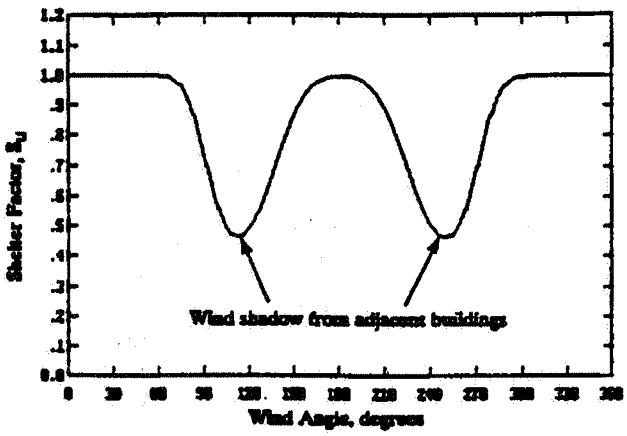

Figure 4: Wind angle dependence of shelter factor, S_U, for the north wall of a house at AHHRF.

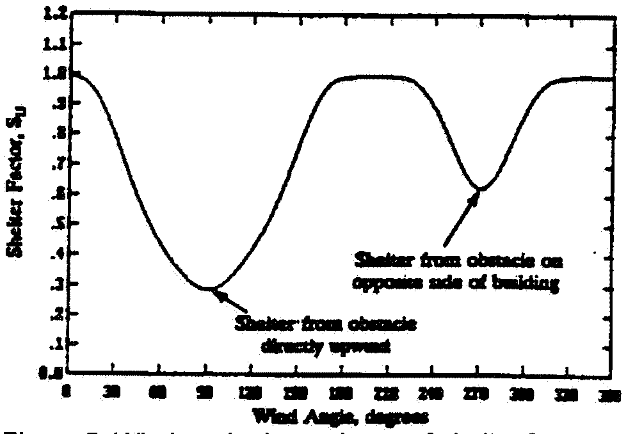

Figure 5: Wind angle dependence of shelter factor, Su, for the east wall of a house at AHHRF.

6 Validation of Improved Leakage Distribution and Wind Pressure Estimates

A detailed description of the measurement facility is given by Wilson and Walker [3]. The house with the most complex leakage distribution is examined here because it is the most difficult to model. In addition to the background leakage of the house (86 cm^2) there is a furnace flue (34 cm^2), a passive ventilation pipe into the basement (59 cm^2) and an open window (30 cm^2).

To separate the effects of the improvements to ventilation predictions from the behaviour of the rest of the model, the measured data will be compared to predictions with and without the improvements. Without the improvements, the window and basement passive vent leakage were included in the distributed leakage of the walls and floor, the wall and floor leakage were evenly distributed over the four walls, and the flue was included in the ceiling leakage. The shelter factor used was the average for all four walls over all wind directions (S_U = 0.79), and the pressure coefficients did not vary with wind angle.

The predictions are evaluated using two parameters - the bias and the absolute error. The bias is the mean of the differences between individual pairs of predicted and measured data. Thus the bias indicates the difference between measurements and predictions over long time periods. The absolute error is the mean of the absolute differences between measurements and predictions. In this case positive and negative errors do not cancel and this provides an estimate of the typical model error for an individual hour. The results are presented in Air Changes per Hour (ACH) using a house volume of 220 m^3. The measured data are sorted into wind and stack dominated parts so that the wind and stack dependence of the predicted and measured ventilation rates may be examined separately.

The computer model used the measured wind speeds, wind directions and indoor and outdoor temperatures to calculate ventilation rates corresponding to every measured ventilation rate, both with and without the improvements. For stack dominated conditions, Figure 6 shows how the model with improvements gives better estimates of the ventilation rate. The upper figure shows every measured data point and the lower figure shows the measured data in bins every 5K of temperature difference, with the error bars representing the standard deviation of the measured data within the bin. For the model, the ventilation rate is calculated for each point, but for clarity, the calculations are also binned every 5K and the average value in each bin is connected by a line. In this case the bias changed from -19% to -1% (negative errors indicate underprediction) and the absolute error from 19% to 8% by including the improved ventilation estimation methods discussed in this paper. These results illustrate the benefit of allowing the large localised leakage sites (the flue, basement pipe and window) to have their own height above grade instead of being included in the distributed leakage.

For wind dominated conditions the measured and calculated data are shown in Figure 7. In this case, the differences are much less clear than for stack dominated ventilation. However, including the leakage distribution and wind pressure calculation improvements decreased the bias from -12% to -4% and the absolute error from 21% to 12%.

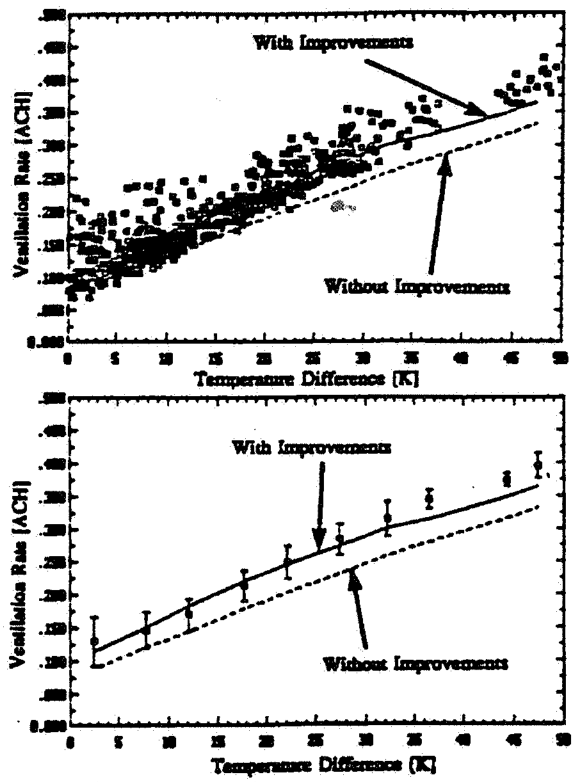

Figure 6: Comparison of measured and predicted stack dominated ventilation rates for house 5 at AHHRF, with a furnace flue, passive vent and an open window (659 hours, mean temperature difference = 15.6K, mean windspeed = 1.4 m/s).

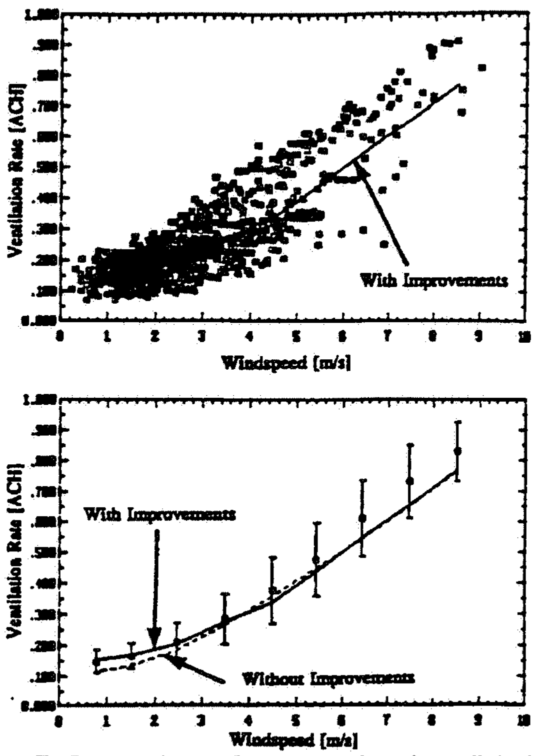

Figure 7: Comparison of measured and predicted wind dominated ventilation rates for house 5 at AHHRF, with a furnace flue, passive vent and an open window (1042 hours, mean temperature difference = 9.6K, mean windspeed = 2.7 m/s).

To obtain a clearer interpretation of the effects of allowing the shelter and pressure coefficients to vary with wind direction, this data set was replotted to show the variation with wind angle in Figure 8. Figure 8 shows binned data only, where the measured data has been binned every 20 degrees of wind direction. As with the other figures the error bars represent the standard deviation of the measured data for each wind direction bin, and the predicted infiltration rates are shown by a straight line connecting their mean values in each bin. Figure 8 shows that constant shelter and pressure coefficients result in underprediction for south winds (when the building is exposed) and over prediction for east and west winds (when the building is sheltered and the pressure coefficients change). The results of the above data comparisons are summarised in Table 1.

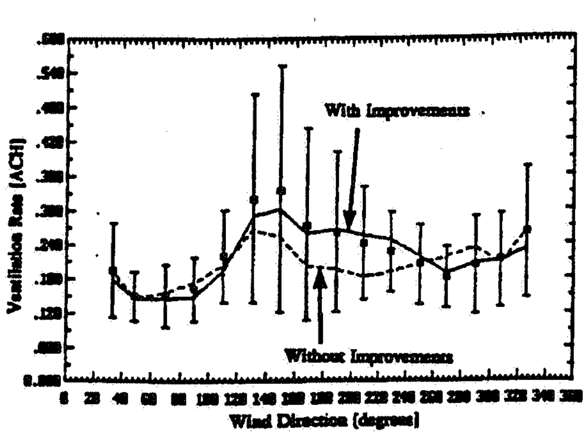

Figure 8: Wind angle dependence of measured and predicted wind dominated ventilation rates for house 5 at AHHRF, with a furnace flue, passive vent and an open window (1042 hours, mean temperature difference = 9.6K, mean windspeed = 2.7 m/s).

	Wind Dominated		Stack Dominated	
	With Improvements	Without Improvements	With Improvements	Without Improvements
Number of points	1042		659	
Mean ΔT	9.6 K		15.6 K	
Mean U	2.7m/s		1.4 m/s	
Mean Measured Ventilation Rate	0.249 ACH		0.202 ACH	
Mean Predicted Ventilation Rate	0.238 ACH	0.220 ACH	0.200 ACH	0.160 ACH
Bias Error	-0.011 ACH -4%	0.030 ACH -12%	-0.002 ACH -1%	-0.038 ACH -19%
Absolute Error	0.031 ACH 13%	0.052 ACH 21%	0.017 ACH 9%	0.038 ACH 19%

Table 1: Summary of differences between measured data and model predictions.

8 Summary

Four concepts have been introduced to improve estimates of ventilation rates in houses. These improvements have been incorporated into a ventilation model (LOCALEAKS) whose predictions have been validated by comparison to several hundred hours of measured ventilation rates and flows through individual leaks. LOCALEAKS was also used without localised leakage and changing shelter and pressure coefficients in order to illustrate the effect of these concepts. In every case the improvement produced ventilation rate predications that were significantly improved (by 10% or more).

The ideas about shelter and pressure coefficients introduced here may be used as input to other ventilation models, and are not restricted to use in LOCALEAKS, because they are parameters that are normally input to a model rather than the functional form of the model itself.

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New Publications

"Raumluftströmung" (Air Flow in Ventilated Rooms)

by Bernd M Hanel,
published by Verlag C F Mueller, Heidelberg 1994;
ISBN 3 7880 7507 4

The book gives a survey of the most important principles and parameters for the solution of problems and tasks in ventilation and air-conditioning within rooms. Forced, mixed and free convection flow and displacement flow are discussed. Empirical, experimental and simple and difficult computational methods are described to determine the air movement and distribution of temperature and concentration. Isothermal and nonisothermal turbulent free and wall jets, and buoyant jets are analysed and the application of free jets and thermal plumes in ventilating techniques are shown. In addition a mathematical model for room air distribution is described, including the models of turbulence and the numerical solutions of two- and three dimensional problems. Several flow patterns are given and the reader can see that this method is very effective for predetermining air movement within rooms and industrial buildings. In the context of free jets, some essential supply openings like slots, grills, wall and ceiling diffusors, and floor mounted inlets are drawn, and their effects on the flow pattern and air quality of the occupied zone are discussed.

This item is available on loan from the AIVC Library, or for purchase from Verlag C F Muller, Postfach 102869, 69018 Heidelberg, Germany, Fax: 06221/489 443, price DM 69.00.

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Minimising Air Infiltration in Office Buildings

by M D A E S Perera, C H C Turner and C R Scivyer

Published by the UK Building Research Establishment, 1994

ISBN 0 85125 634 1

This report aims to promote greater awareness of the importance of minimising air infiltration and how this can improve building performance, particularly in relation to the internal environment. It has been produced in support of new requirements on airtightness which have been incorporated in Approved Document L (1995 edition) which supports the Building Regulations (England and Wales).

The report is intended as an outline guide to design. It sets out the principles of providing an effective airtightness layer and advises on some of the common pitfalls which can reduce the performance of this layer. The drawings are not intended to highlight the airtightness performance of specific components, but to draw attention to airtightness issues and to identify some typical details that need to be addressed.

The contents include: understanding infiltration; infiltration paths; benefits of minimising infiltration; infiltration and climate-responsive design; identifying zones requiring protection; designing a tight envelope; building specification; inspection during construction; diagnosis and testing; some case studies - new construction; remedial work on existing buildings.

New Publications

Natural Ventilation in Non-Domestic Buildings

BRE Digest 399

Published by UK Building Research Establishment, October 1994

ISBN 0 85125 645 7

Adequate ventilation is essential for the well being and health of building occupants and the provision of fresh air was traditionally met by natural means. This approach has partly given way to air conditioning in response to the perceived need to cool modern buildings, which tended to suffer from high solar heat gains, poor natural daylighting and use of many energy intensive appliances.

Increased concern over the adverse environmental impact of energy use has encouraged the design and construction of energy efficient building, many of them suited to natural ventilation. It can provide year round comfort, with good user control, at minimum capital cost and with negligible maintenance.

This Digest gives the professional design team and building users background information and design guidance on using natural ventilation in energy efficient non-domestic buildings.

Copies of the above reports are available on loan from AIVC, or by contacting the BRE Bookshop, Building Research Establishment, Garston, Watford WD2 7JR, UK, Tel: +44 (0)1923 664444, Fax: +44 (0)1923 664444.

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The Third International Conference on Carbon Dioxide Utilisation (ICCDU)
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Indoor Air Quality, Ventilation and Energy Conservation in Buildings
2nd International Conference
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IAI Indoor Air International Conference
Scientific and Regulatory Aspects of Air Quality Management
7-9 June 1995
SEC Conference Centre, St Petersburg, Russia
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BIB1 (1993) Ventilation and infiltration characteristics of lift shafts and stair wells
BIB2 (1994) Garage Ventilation: Summarises research into the health, energy and design aspects of the various systems used in garage ventilation.
BIB3 (1994) Natural ventilation: Covers the main elements of natural ventilation research, the fundamental equations, driving forces and associated factors, as well as useful reports which focus on modelling and calculating natural ventilation air flows.

AIVC CONFERENCE PROCEEDINGS

AIVC Conference Proceedings nos 1-9 are available as individual papers, or in microfiche form. Details of contents can be forwarded on request.
10th 'Progress and trends in air infiltration and ventilation research' Espoo, Finland, 1989;
11th 'Ventilation System Performance' Belgirate, Italy, 1990;
12th 'Air Movement and Ventilation Control within Buildings', Ottawa, Canada, 1991, 3 volumes.;
13th 'Ventilation for Energy Efficiency and Optimum Indoor Air Quality', France, 1992;
14th 'Energy Impact of Air Infiltration and Ventilation', Denmark, 1993
15th 'The role of ventilation', Buxton, UK, 1994

LITERATURE LISTS

(Available to participants only - free of charge)
1) Pressurisation - infiltration correlation: 1. Models.
2) Pressurisation - infiltration correlation: 2. Measurements.
3) Weatherstripping windows and doors.
4) Caulks and sealants.
5) Domestic air-to-air heat exchangers.
6) Air infiltration in industrial buildings.
7) Air flow through building entrances.
8) Air infiltration in commercial buildings.
9) Air infiltration in public buildings.
10) Carbon dioxide controlled ventilation.
11) Occupancy effects on air infiltration.
12) Windbreaks and shelterbelts.
13) Air infiltration measurement techniques.
14) Roofs and attics.
15) Identification of air leakage paths.
16) Sick buildings.
17) Flow through large openings.
18) Control of cross contamination from smokers.
19) Location of exhausts and inlets.
*For list of participating countries see back page.

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