Lawrence Berkeley National Laboratory

Recent Work

Title

Infiltration Models for Multicellular Structures: A Literature Review

Permalink

<https://escholarship.org/uc/item/5rp2060t>

Journal

Energy and buildings, 8(2)

Authors

Feustel, H.E.
Kendon, V.M.

Publication Date

1985-04-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY

APPLIED SCIENCE DIVISION

JUL 24 1985

LIBRARY AND
DOCUMENTS SECTION

To be published in Energy and Buildings, Vol. 8,
No. 2, pp. 123-136, 1985

INFILTRATION MODELS FOR MULTICELLULAR STRUCTURES:
A Literature Review

H.E. Feustel and V.M. Kendon

April 1985

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy...
which may be borrowed for two weeks.*

**APPLIED SCIENCE
DIVISION**

LBL-17588
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

To be Published in Energy and Buildings, Vol. 8, No. 2, pp. 123-136, 1985.

Infiltration Models for Multicellular Structures - A Literature Review

H. E. Feustel and V. M. Kendon

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA. 94720

April 1985

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Abstract

Infiltration models are used to simulate the rates of incoming and outgoing air flows for a building with known leakage under given weather and shielding conditions. Additional information about the flow paths and air-mass flows inside the building can only be made available by using multichamber infiltration models. Our review of the literature revealed the existence of 15 multichamber infiltration models, all developed between 1966 and 1983 and differing significantly in the number of cells they can handle and depending on the date of their development. These programs use similar flow equations but most differ in the description of the building and the algorithm provided for solving the set of nonlinear equations. In this literature review, we found that only a few of the 15 models are able to describe and simulate the ventilation system and the interrelation of mechanical and natural ventilation.

Introduction

The LBL infiltration model was developed in 1980 to simulate air infiltration of single cell structures, such as single-family houses, under given weather conditions.¹ A high percentage of the existing buildings, however, have floor plans that more closely resemble multichamber structures, which cannot be treated by singlecell models. This literature review is intended to be a first step in the development of a multichamber infiltration model.

The advantage of multichamber models, besides being able to simulate infiltration in larger buildings, is their ability to calculate mass flow interactions between the different zones. Knowing the air-mass flow in buildings is important for several reasons, significantly because:

- exchange of outside air with the air inside the building is necessary for its ventilation;
- energy is consumed to heat or cool the incoming air up to inside comfort temperature.
- air is needed for combustion and exhaust gas for open fireplaces in different zones.
- airborne particles and germs are transported by air flow in buildings.
- air flow determines smoke distribution in case of fire.

The air-mass flow distribution for a given building is caused by pressure differences, whether evoked by wind, thermal buoyancy, mechanical ventilation systems or any combination of the above. The distribution of openings in the building shell and the inner paths influence the air flow, too. The openings can be varied by the occupants, which can lead to significant differences in the pressure distribution inside the building. Figure 1 shows the influences on the air-mass flow distribution in detail.

FIGURE 1: INFLUENCES ON THE AIR-MASS FLOW DISTRIBUTION IN BUILDINGS

In terms of air-mass flow, buildings are complicated interlacing systems of flow paths. In this grid-system the joints are the rooms of the building and the connections between the joints simulate the flow paths and include the flow resistances caused by open or closed doors and windows or air leakage through the walls. The boundary conditions for the pressure can be described by the grid points outside the building. The wind pressure distribution depends on the velocity and the direction of the wind, the terrain surrounding the building, and the shape of the building. The air flow distribution for the building can be calculated if the physical interrelationship between the flow resistance and the air flow is known for all flow paths, and there is no temperature difference between outside and inside air. Differences in density of the air, due to differences between outside and inside air temperatures, cause further pressures in the vertical direction, again influencing the air-mass flow.

Mechanical ventilation can also be included in this network. The duct system can be treated like the other flow paths in the building. The advantage for calculating air flow distribution effects of mechanical ventilation systems is that the duct path ways, as well as their connections with the building, are known. In the case of mechanical ventilation systems the fan is the source of pressure differences, lifting the pressure level between two joints according to the characteristic curve of the fan.

Because of the nonlinear dependency of the volume flow rate on the pressure difference, the pressure distribution for a building can be calculated only by using a method of iterations. Large computer storage

is necessary to describe buildings with arbitrary floor plans and to solve the set of nonlinear equations.

Infiltration Model Availability

The Air Infiltration Centre (AIC) recently published a review of ten mathematical infiltration models² that have been developed in five of the AIC participating countries. Only five of those described are multichamber infiltration models. An additional literature survey produced 26 papers describing 15 different models developed in eight countries. The additional ten multichamber models described in this report show the necessity of an extended search.

In addition to the scarcity of computer programs for modelling infiltration in multicellular structures, the descriptions of existing programs were not adequate for our purposes. Accordingly we developed a questionnaire and mailed it to all program authors. 75% of the questionnaires were returned. Of those that were not returned, we were usually able to determine the information from the reviewed literature. In cases where the reviewed papers did not give us a reasonable answer to a certain problem or where information was missing from a returned questionnaire, we entered a question mark in the questionnaire.

The completed questionnaires are reproduced in Appendix C. The addresses shown are the current addresses of the authors, rather than the addresses of the institution where the program was developed. Equations and references are reproduced separately in Appendices A and B.

Discussion

Whereas singlecell models used a variety of approaches², the investigated multichamber models relied on similar equations. The flow equation used to describe the air flow characteristics of the buildings is similar to the one describing measured results for air flow through building components.³⁻⁹ Twelve of the fifteen programs use an empirical power-law equation (even though the pressure exponent may differ from 0.5 to 1.0, depending on the nature of flow). A comparison of air leakage measurements conducted in 196 houses by means of the blower door technique showed, for the whole house, a mean value for the exponent of 0.66,¹⁰ which is in good agreement with the measured flow characteristics of building components.

Six of the fifteen models use Newton's method of iteration for solving the set of nonlinear equations. However, the method of solving this problem varied from simple one-dimensional methods²³ to the two-dimensional methods described above. The differences are in the necessary storage and the quality of convergence.

Unfortunately, the programs reviewed here have one negative point in common: most of them are available only to a limited number of users.

The programs differ most in their ability to simulate mechanical ventilation systems. Eight of them are unable to simulate forced ventilation at all, or at least the references do not indicate any handling of ventilation systems; two use the simplified method of setting a fixed air-mass flow for unbalanced mechanical ventilation systems, and only five describe mechanical ventilation systems by means of fan and duct

characteristics. The latter are able to simulate the interaction of mechanical and natural ventilation.

The difficulties of measuring infiltration in multichamber structures means that few such models have been validated properly, if at all. The possibility of doing piecemeal validations of certain algorithms has been considered; e.g. the algorithms for air flow through open doorways or air flow through cracks have been tested separately.¹¹ Even though infiltration cannot be measured for an entire building at once, measuring a few cells of the whole structure could still provide a severe test for existing models.

These measurement data are important not only for validation purposes but also as a means of further understanding of air movement in large multizoned buildings. We need to identify the critical variables in different building types in order to develop more accurate input data, and ultimately, more accurate models. Wind pressure coefficients, for example, represent a factor that needs further study, and collating of existing data should help our efforts to simplify data requirements.

Conclusion

Multichamber infiltration models treat the true complexity of flows in a building in recognizing effects of internal flow restrictions. They require extensive information about flow characteristics and pressure distributions, and, in many cases, are too complex to justify their use to predict flow for simple structures, such as single-family residences.¹²

Most multicellular models presently in use are not available to the public or are written as research tools, rather than for the use of professional engineers or architects. There is an obvious need for a simplified multichamber infiltration model capable of providing the same accuracy as the established singlecell models.

Acknowledgments

We should like to acknowledge the cooperation of the program authors in responding to our questionnaires, for without this information the different programs could not have been compared. We must also acknowledge Peter Cleary, Alan Meier and Laural Cook for their critical review and helpful comments. No undertaking of this kind escapes the welcome scrutiny of all our colleagues at the Energy Performance of Buildings Group. In particular we appreciate the valuable comments of Richard Diamond during the writing process.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

1. Sherman, M.H. and D.T. Grimsrud; Measurement of Infiltration using Fan Pressurization and Weather Data. Proceedings of the 1st AIC Conference, Windsor, England (1980)
2. Liddament M. and C. Allen; The Validation and Comparison of Mathematical Models of Air Infiltration. Air Infiltration Centre, Technical Note AIC 11 (1983)
3. Hopkins L.P. and B. Hansford; Air Flow through Cracks. BSE 42 (1974), No. 9, PP 123-131
4. Holz D.; Zusammenhang zwischen der Fugendurchlaessigkeit von Fenstern und dem Luftwechsel im Haus. Forschungsbericht T80-075, Bundesministerium fuer Forschung und Technologie, (1980)
5. Peterson F.; On Flow in Narrow Slots applied to Infiltration. Proceedings of the 3rd AIC Conference, London (1982)
6. Raisch E.; Die Waerme- und Luftdurchlaessigkeit von Fenstern verschiedener Konstruktion. GI Gesundheits-Ingenieur 45 (1922), PP. 99-105
7. Reiher H., K. Fraass and E. Settle; Ueber die Frage der Luft- und Waermedurchlaessigkeit von Fenstern. 1. Teilbericht, Waermewirtschaftliche Nachrichten 6 (1932/1933), PP. 45-52 and PP. 55-59
8. Schuele W.; Luftdurchlaessigkeit von Fenstern. GI Gesundheits-Ingenieur 83 (1962), No. 6, PP. 181-184
9. Sigwart K.; Luftdurchlaessigkeit von Holz- und Stahlfenstern. GI Gesundheits-Ingenieur 55 (1932), PP. 515-517
10. Sherman M. H., D. J. Wilson and D. E. Kiel; Variability in Residential Air Leakage. Proceedings of the ASTM-Symposium on Measured Air Leakage Performance of Buildings, Philadelphia (1984)
11. Shaw B. H. and W. Whyte; Air movement through doorways - the influence of temperature and its control by forced air flow. BSE 42 (1974), No. 12, PP. 210-218
12. ASHRAE Handbook of Fundamentals, Natural Ventilation and Infiltration, Chapter 22, to be published in 1985.
13. Etheridge D. W. and D. K. Alexander; The British Gas Multi Cell Model for Calculating Ventilation. ASHRAE-Transactions, Vol 86 (1980), Part II, PP. 808-821.
14. Etheridge D. W.; Crack Flow Equation and Scale Effect. Building and Environment, Vol 12 (1977), PP. 181-189.
15. Etheridge D. W. and J. A. Nolan; Ventilation Measurements at Model

Scale in a Turbulent Flow. Building and Environment, Vol 14 (1979), PP. 53-64.

16. Etheridge D. W. and P. Phillips; The Prediction of Ventilation Rates in Houses and the Implications for Energy Conservation. Proceedings of C.I.B. Steering Group S17 Meeting, Holzkirchen (1977), PP. 46-67.
17. Evers E. and A. Waterhouse; A Computer Model for Analysing Smoke Movement in Buildings. Building Research Establishment CP 69/78 (1978)
18. Jackman P. J.; A Study of the Natural Ventilation of tall Office Buildings. JIHVE, Vol 38 (1970), PP. 103-118
19. Jackman P. J.; Heat Loss in Buildings as a Result of Infiltration. BSE, Vol 42 (1974), PP. 6-15
20. Gabrielsson J. and P. Porra; Calculation of Infiltration and Transmission Heat Loss in Residential Buildings by Digital Computers JIHVE, Vol 35 (1968), PP. 357-368
21. Sander D. M. and G. T. Tamura; A FORTRAN IV Program to Simulate Air Movements in Multi-Storey Buildings. DBR Computer Program No. 35, National Research Council of Canada, (1973).
22. Sander D. M.; FORTRAN IV Program to Calculate Air Infiltration in Buildings. DBR Computer Program No. 37, National Research Council of Canada, (1974).
23. Shaw C. Y.; D. M. Sander and G. T. Tamura; A FORTRAN IV Program to Simulate Stair-Shaft Pressurization System in Multi-Storey Buildings DBR Computer Program No. 38, National Research Council of Canada, (1974).
24. Walton G. N.; Thermal Analysis Research Program Reference Manual NBSIR 83-2655, U.S. Department of Commerce, (1983).
25. Irving S. J. and A. P. Wilson; Validation of a Smoke Movement Program. Building Services Engineering Research & Technology, Vol. 2 (1981), No. 4, PP. 151-159.
26. Irving S. J.; The Computer Simulation of Smoke Movement during Building Fires. Fire Prevention Science and Technology, No. 22, (1979), PP. 3-8
27. Pedersen Ch. F.; Datamatberegning af Luftstromninger i Bygninger. Statens Byggeforskningsinstitut, Notat 72, (1977)
28. deGids W. F.; Calculation Method for the Natural Ventilation of Buildings. Publication No. 632 of the TNO Research Institut for Environmental Hygiene, Delft, (1977)
29. Brinkmann W.; Zur Bestimmung des Lueftungswaermebedarfs hoher

Gebäude. Dissertation, Technische Universität Berlin, (1980)

30. Feustel H. E.; Beitrag zur theoretischen Beschreibung der Druck- und Luftmassenstromverteilung in natürlich und maschinell gelüfteten Gebäuden. Fortschritt-Berichte der VDI-Zeitschriften, Reihe 6, Nr.151 (1984)
31. Feustel H. E. and H. Esdorn; Mass Flow Distribution in High-Rise Buildings with Forced ventilation Systems. Proceedings of the International Conference on System Simulation in Buildings, Liege, (1982)
32. Hausladen G.; Wohnungslüftung, Untersuchung der verschiedenen Lüftungsarten bzw. Lüftungspraktiken unter hygienischen, bauphysikalischen und energetischen Gesichtspunkten. Dissertation Technische Universität München, (1980), Fortschritt-Berichte der VDI Zeitschriften, Reihe 6, Nr. 73
33. Hausladen G.; Luftwechsel in Wohnungen. Heizung Lüftung Haustechnik (1978), No. 1, PP. 21-28
34. Krueger W. and G. Hausladen; Einfluss von Wind- und thermischen Kräften auf das Betriebsverhalten von mechanisch betriebenen Entlüftungsanlagen in mehrgeschossigen Wohngebäuden. Forschungsbericht des Instituts fuer Haustechnik, Technische Universität München (1979)
35. Cockroft J. P.; Air Flows in Buildings. Proceedings of the Environment Inside Buildings Symposium, Southend on Sea, (1979)
36. Cockroft J. P.; Validation of Buildings and Systems Energy Prediction using Real Measurements. Computer Aided Design, Vol. 14 (1982), No. 1, PP. 39-43
37. Billsborrow R. E.; Digital Analogue for Natural Ventilation Calculations Report No. BS 6, Department of Buildings Science, University of Sheffield, (1973)
38. Pitts A. C. and I. C. Wards; A Review of the Prediction and Investigation of Air Movement in Buildings. Report No. BS 69, Department of Buildings Science, University of Sheffield, (1983)
39. Svetlov K. S.; Calculations of Air Infiltration in Multi-Story Buildings using Electronic Computers. Vodosnabzie i Sanitarna Tekhnika, Vol. 11 (1966), HVRA-Translation 122

APPENDIX A

Nomenclature

SYMBOL	DESCRIPTION	UNITS
A	area	m^2
B	constant	--
C	crack flow coefficient	$m^3/m \ h \ Pa^n$
CR	correction term	Pa
D	flow coefficient	$m^3/h \ Pa^n$
E	effective leakage area	cm^2
F	mass flow rate	kg/h
H	height	m
K	constant	--
L	crack length	m
P	pressure	Pa
Q	volume flow rate	m^3/h
S	resistance	$h \ Pa/m^3$
T	temperature	$^{\circ}K$
a,b,c	coefficients	--
c_p	surface pressure coefficient	--
f	function of	--
g	gravity	m/s^2
i,m	number of ductwork components	--
n	flow exponent	--
t	temperature	$^{\circ}C$
v	wind speed	m/s
z	depth of crack	m
ρ	air density	kg/m^3
μ	viscosity of air	m^2/s
λ	friction factor	--
ξ	fitting loss coefficient	--
θ	absolute temperature	K

Subscripts

o	outside
f,i,r,s	locations in the duct system
i	inside
j	iteration step
j+1	iteration step + 1
s	stack

v	velocity
0	reference
NET	inside

APPENDIX B

TABLE 1: Equations used for Flow through Cracks

- 1 A) $F = D \times \Delta P^n$
- 1 B) $Q = D \times \Delta P^n$
- 1 C) $\frac{Q}{3600} = \frac{D}{3600} \times \Delta P^{1/n}$
- 1 D) $\Delta P = a \times Q^2 + b \times Q$
- 1 E) $Q = C \times L \times \Delta P^n$
- 1 F) $F = K \times \Delta P^x$
- 1 G) $Q = C \times A \times \Delta P^n$
- 1 H) $\Delta P = \left(\frac{Q}{K \times L}\right)^n$
- 1 I) $\Delta P = 0.5 \times L \times (C \times Q)^2$

TABLE 2: Equations used for Flow through Large Openings

- 2 A) $F = D \times \Delta P^n$
- 2 B) $Q = D \times \Delta P^n$
- 2 C) $\frac{Q}{3600} = \frac{D}{3600} \times \Delta P^{1/n}$
- 2 D) $Q = A \times C \times \left(\frac{2 \Delta P}{C}\right)^{1/2}$
- 2 E) $F = K \times \Delta P^x$
- 2 F) $Q = A \times (2 \Delta P)^{1/n} \times (1/C)^{1/2}$
- 2 G) $\Delta P = S \times Q^2$

TABLE 3: Equations used for Flow through Duct Work

$$3 A) Q = C \times A \left[P_f - (\rho_f \times g \times (H_r - H_f + \frac{H_i}{2} - H_s) - P_i + (\rho_i \times g \times (H_s - \frac{H_i}{2})) \right]^n$$

$$3 B) Q = A \times \left(\frac{2}{\rho} \right)^{1/2} \times \sum_{i=1}^m \left(\frac{1}{k} \right)_j^{1/2} \times \Delta P^{1/2}$$

$$3 C) P - \frac{\rho}{2} \times v^2 \times (1 + \sum \zeta) + \Delta P_{VE} - P_D = 0$$

$$3 D) \Delta P = \left[K + \frac{f_L}{D} \right] \frac{g}{H^2 \times D^4 \times \rho} Q^2$$

$$3 E) Q = A_{NET} \times (2 \Delta P)^{1/n} \left(\frac{1}{\rho} \right)^{1/2} \left(\frac{\lambda \times 1}{d} + \sum \zeta \right)$$

TABLE 4: Equations used for Fan Flow Characteristics

$$4 A) Q = K_1 + K_2 \times \Delta P + K_3 \times \Delta P^2$$

$$4 B) \Delta P = K_1 + K_2 \times Q + K_3 \times Q^2$$

$$4 C) \Delta P = \Delta P_o - K_1 \times Q - K_2 \times Q^2$$

$$4 D) \Delta P = B \times n^2 \times D^2 + \frac{Q^2}{A^2 \times D^4}$$

$$4 E) \Delta P = f(Q_v)$$

TABLE 5: Equations used for Wind Pressure

$$5 A) \quad \Delta P = \frac{\rho}{2} \times v^2$$

$$5 B) \quad \Delta P = C \times \frac{\rho_o}{2} \times v^2$$

$$5 C) \quad \Delta P = C \times \frac{\rho}{2} \times v_o^2$$

$$5 D) \quad \Delta P = C \times \frac{\rho}{2} \times v(H)^2$$

$$5 E) \quad \Delta P = \frac{\rho}{2} \times v^2$$

with $v = v_o \times 2334 \times (1 + 2.8 \log (H + 4.75))$

TABLE 6: Equations used for Thermal Buoyancy

$$6 A) \quad \Delta P = \rho \times g \times \Delta H$$

$$6 B) \quad \Delta P = (\rho_o - \rho_i) \times g \times (H - H_o)$$

$$6 C) \quad \Delta P = 3462 \times (H - H_o) \times \left[\frac{1}{T_o} - \frac{1}{T_i} \right]$$

$$6 D) \quad \Delta P = (\rho_o - \rho_i) \times g \times H$$

$$6 E) \quad \Delta P = (\rho_o - \rho_i) \times g \times H \times (X - 0.5 - N/2) \times b + c$$

$$6 F) \quad Q = (C_D \times A/n) \times (\Delta \theta \times g \times \frac{H}{\theta})^{1/2}$$

$$6 G) \quad \Delta P = \rho_o \times \left(\frac{T_i - T_o}{T_i \times T_o} \right) \times T_o \times g \times H$$

TABLE 7: Equations used for Outside Pressure Fluctuations

$$7 A) \quad (\Delta \bar{P}^{-2})^{0.5} = 0.5 \times (\bar{P}_o^{-2})^{0.5}$$

$$7 B) \quad Q_v = 1/2 \times A_{NET} \times (0.001v^2 + 0.0035 \times H \times \Delta T + 0.01)^{1/2}$$

TABLE 8: Algorithm to Solve the Nonlinear Set of Equations

$$8 A) \quad P_{j+1} = P_j \pm \left(\frac{Q_j}{C_j A_j} \right)^{n_j}$$

$$8 B) \quad P_{j+1} = P_j - \frac{\Sigma Q}{\Sigma Q}$$

$$8 C) \quad CR = \frac{\Sigma D \times \Delta P^{1/n}}{\Sigma \left| \frac{D}{n} \times \Delta P^{((1/n)-1)} \right|}$$

$$8 D) \quad \Sigma F = 0$$

$$8 E) \quad P_{j+1} = P_j - \text{Correction}$$

APPENDIX C

Questionnaire sent to authors of computer programs

Name and Address: D. W. Etheridge
British Gas Corporation
Watson House
Peterborough Road
London SW6 3HN
United Kingdom

References: 13-16

Equation used for

- flow through cracks: 1D)
- flow through large openings: 2D)
- flow through duct work: ---
- fan flow characteristics: constant
- wind pressure: 5C)
- thermal buoyancy: 6B)
- outside pressure fluctuation: 7A)
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: Internal reference pressure adjusted until flow errors negligible
- equation: ?

Maximal number of rooms:	VENT 1	VENT 2
(including shafts, corridors, etc.)	40	2

Limits on number of

- openings per room:	no limits per room	40
- shafts, corridors, floors:	40/40/40	0
- mechanical ventilation systems:	one flow per opening	1

Programme language:	FORTRAN 77	BASIC
Programme available:	limited availability	
Written for computer type:	HARRIS and CAI ALPHA	TEKTRONIX 40/51 HP 87

Name and Address: P. R. Warren and M. D. A. E. S. Perera
Building Research Establishment
Bucknalls Lane
Garston, Watford WD2 7JR
United Kingdom

References: 17

Equation used for

- flow through cracks: 1H)
- flow through large openings: 2D)
- flow through duct work: 3D)
- fan flow characteristics: 4D)
- wind pressure: 5B)
- thermal buoyancy: 6F)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: BREEZE
- equation: Iterative technique using
linear approximation to
a set of nonlinear equations
including Q and P.

Maximal number of rooms: 60
(including shafts, corridors, etc.)
Limits on number of

- openings per room: not restricted; one cell can
be joined to another by only
one flow path
- shafts, corridors, floors: max. no. of rooms; 10 floors;
- mechanical ventilation systems: no restriction except that they
conform to an overall size
restriction of 60 zones

Programme language: FORTRAN 77
Programme available: Yes, but not user-friendly
Written for computer type: VAX; it also has been im-
plemented on TEL 1904S

Name and Address: P. J. Jackman
Building Services Research
and Information Association
Old Bracknell Lane West
Bracknell, Berkshire RG12 4AH
United Kingdom

References: 18,19

Equation used for

- flow through cracks: 1C)
- flow through large openings: 2C)
- flow through duct work: not applicable
- fan flow characteristics: not applicable
- wind pressure: 5B)
- thermal buoyancy: 6C)
- outside pressure fluctuation: not applicable
- circulation flow on large openings: not applicable

Algorithm to solve the nonlinear set of equations

- name of algorithm: Hardy Cross to establish reasonable first estimate
followed by Cholesky triangular factorization
- equation: 8C)

Maximal number of rooms: limited by available computer
memory size

(including shafts, corridors, etc.)

Limits on number of

- openings per room: no particular limit
- shafts, corridors, floors: no particular limit
- mechanical ventilation systems: no particular limit; mechanical
ventilation is simulated as
specified air flow rate per room.

Programme language:

FORTRAN

Programme available:

for use by BRSIA staff only

Written for computer type:

PRIME 300

Name and Address: J. Gabrielsson
Ekono Association for
Power and Fuel Economy
P.O. Box 27
00131 Helsinki 13
Finland

References: 20

Equation used for

- flow through cracks: 1G)
- flow through large openings: ---
- flow through duct work: 3A)
- fan flow characteristics: interpolated from fan curve
- wind pressure: 5E)
- thermal buoyancy: 6B)
- outside pressure fluctuation: as in ASHRAE procedure for determining heating and cooling loads for computerized energy calculations Algorithms for building's heat transfer subroutines, New York 1971.
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: ---
- equation: 8A)

Maximal number of rooms: 725
(including shafts, corridors, etc.)

Limits on number of

- openings per room: unlimited
- shafts, corridors, floors: 5; 720; 720
- mechanical ventilation systems: 20

Programme language:

FORTRAN 77

Programme available:

limited (Finnish manuals only)

Written for computer type:

VAX 11/780

Name and Address: C. Y. Shaw
Bldg. M-24 Division of Building Research
NRC, Montreal Rd.
Ottawa, KIA OR6
Canada

References: 21-23

Equation used for

- flow through cracks: 1F)
- flow through large openings: 2E)
- flow through duct work: constant
- fan flow characteristics: ---
- wind pressure: cp (wind tunnel measurements)
- thermal buoyancy: 6D)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: CP 45
- equation: 8D)

Maximal number of rooms: 25 components and 8 shafts
(including shafts, corridors, etc.)

Limits on number of

- openings per room: 4
- shafts, corridors, floors: 1
- mechanical ventilation systems: up to 8

Programme language: FORTRAN IV
Programme available: yes
Written for computer type: IBM 360

Name and Address: G. N. Walton
National Bureau of Standards
BR/B114
Washington D.C. 20234
United States of America

References: 24

Equation used for

- flow through cracks: 1A)
- flow through large openings: 2A)
- flow through duct work: ---
- fan flow characteristics: ---
- wind pressure: 5A)
- thermal buoyancy: 6A)
- outside pressure fluctuation: user input
- circulation flow on large openings: by multiple large openings

Algorithm to solve the nonlinear set of equations

- name of algorithm: Newton (modified)
- equation: 8E)

Maximal number of rooms:
(including shafts, corridors, etc.)
Maximal number of rooms:

it is intended that the
program be compiled
with the appropriate
values of a few para-
meter statements to
match the program
to the problem

Limits on number of

- openings per room:
- shafts, corridors, floors:
- mechanical ventilation systems:

Programme language:
Programme available:
Written for computer type:

FORTRAN 77
yes
SPERRY 1100 (also running
on VAX and IBM)

Name and Address: S. J. Irving
The Oscar Faber Partnership
Marlborough House
Upper Marlborough Rd.
St. Albans, Herts, AL1 3UT
United Kingdom

References: 25,26

Equation used for

- flow through cracks: 1B)
- flow through large openings: 2B)
- flow through duct work: ---
- fan flow characteristics: 4A)
- wind pressure: 5B)
- thermal buoyancy: 6B)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: Newton-Raphson
- equation: 8B)

Maximal number of rooms: 300
(including shafts, corridors, etc.)

Limits on number of

- openings per room: 120
- shafts, corridors, floors: no limits within the
- mechanical ventilation systems: above constraints.

Programme language: FORTRAN IV
Programme available: limited availability
Written for computer type: PRIME 50 series machine

Name and Address: Ch. F. Pedersen
 Statens Byggeforskningsinstitut
 Postboks 113
 DK- 2970 Horsholm
 Denmark

References: 27

Equation used for

- flow through cracks: 11)
- flow through large openings: ?
- flow through duct work: ?
- fan flow characteristics: ?
- wind pressure: ?
- thermal buoyancy: ?
- outside pressure fluctuation: ?
- circulation flow on large openings: ?

Algorithm to solve the nonlinear set of equations

- name of algorithm: Nodes and loops a la Kirchhoff
- equation: ?

Maximal number of rooms: 100
 (including shafts, corridors, etc.)

Limits on number of

- openings per room: ?
- shafts, corridors, floors: ?
- mechanical ventilation systems: ?

Programme language: ?

Programme available: ?

Written for computer type: ?

Name and Address: W. F. deGids
Institute for Environmental
Hygiene - TNO
P. O. Box 214
NE-2600 AE Delft
Netherlands

References: 28

Equation used for

- flow through cracks: 1E)
- flow through large openings: 2F)
- flow through duct work: 3E)
- fan flow characteristics: 4E)
- wind pressure: 5B)
- thermal buoyancy: 6G)
- outside pressure fluctuation: 7B)
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: K-Newton
- equation: 8D)

Maximal number of rooms: 50
(including shafts, corridors, etc.)

Limits on number of

- openings per room: total number of connections
- shafts, corridors, floors: smaller than 200
- mechanical ventilation systems:

Programme language: HPL
Programme available: no
Written for computer type: HP 9825/HP 9816

Name and Address: W. Brinkmann
Bundesbaudirektion Berlin
Fasanenstrasse 87
D-1000 Berlin 12
Federal Republic of Germany

References: 29

Equation used for

- flow through cracks: 1E)
- flow through large openings: ---
- flow through duct work: ---
- fan flow characteristics: ---
- wind pressure: 5D)
- thermal buoyancy: 6B)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: ---
- equation: The exact nonlinear equations were solved to determine the volume flow rate. The balance of in- and outflowing air was determined by iteration (variation of the neutral pressure level NPL)

Maximal number of rooms:
(including shafts, corridors, etc.)

In horizontal direction (per floor):
3 groups of rooms; outside group
divided in windward and leeward flats,
inner group (shafts), middle group
(corridors) combine the diff. groups
In vertical direction: 30

Limits on number of

- openings per room: one to each attached region
- shafts, corridors, floors: unlimited; one per floor; 30
- mechanical ventilation systems: no mechanical ventilation

Programme language:

HP-Special

Programme available:

no

Written for computer type:

HP

Name and Address: H. E. Feustel
Lawrence Berkeley Laboratory
Building 90, Room 3074
Berkeley, Ca 94720
United States of America

References: 30,31

Equation used for

- flow through cracks: 1E)
- flow through large openings: ---
- flow through duct work: 3B)
- fan flow characteristics: 4B)
- wind pressure: 5D)
- thermal buoyancy: 6B)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: Newton
- equation: 8B)

Maximal number of rooms: 200
(including shafts, corridors, etc.)

Limits on number of

- openings per room: unlimited
- shafts, corridors, floors: no limit within the above constraints
- mechanical ventilation systems: 6

Programme language: FORTRAN IV
Programme available: no
Written for computer type: CDC CYBER

Name and Address: G. Hausladen
Schiedel GmbH & Co
Lerchenstrasse 9
Postfach 50 05 65
D-8000 Munich 50
Federal Republic of Germany

References: 32-34

Equation used for

- flow through cracks: 1E)
- flow through large openings: ---
- flow through duct work: 3C)
- fan flow characteristics: 4C)
- wind pressure: 5B)
- thermal buoyancy: 6E)
- outside pressure fluctuation: ---
- circulation flow on large openings: ---

Algorithm to solve the nonlinear set of equations

- name of algorithm: ?
- equation: ?

Maximal number of rooms: ?
(including shafts, corridors, etc.)

Limits on number of

- openings per room: 4
- shafts, corridors, floors: 1;0;?
- mechanical ventilation systems: ?

Programme language: ?

Programme available: ?

Written for computer type: ?

Name and Address: J. P. Cockroft
Building Services
Research Unit
University of Glasgow
3 Lillybank Gardens
Glasgow G12 8RZ
United Kingdom

References: 35,36

Equation used for

- flow through cracks:	1E)
- flow through large openings:	not specified
- flow through duct work:	?
- fan flow characteristics:	?
- wind pressure:	?
- thermal buoyancy:	?
- outside pressure fluctuation:	?
- circulation flow on large openings:	not specified

Algorithm to solve the nonlinear set of equations

- name of algorithm:	?
- equation:	?

Maximal number of rooms: ?
(including shafts, corridors, etc.)

Limits on number of

- openings per room:	?
- shafts, corridors, floors:	?
- mechanical ventilation systems:	?

Programme language: ?

Programme available: ?

Written for computer type: ?

Name and Address: R. E. Bilsborrow
Department of Building Science
Faculty of the Architectural Studies
University of Sheffield
Sheffield S10 2TN
United Kingdom

References: 37,38

Equation used for

- flow through cracks: 1E)
- flow through large openings: ?
- flow through duct work: ?
- fan flow characteristics: ?
- wind pressure: ?
- thermal buoyancy: ?
- outside pressure fluctuation: ?
- circulation flow on large openings: ?

Algorithm to solve the nonlinear set of equations

- name of algorithm: ?
- equation: ?

Maximal number of rooms: 211
(including shafts, corridors, etc.)

Limits on number of

- openings per room: 4
- shafts, corridors, floors: 1;?;10
- mechanical ventilation systems: ?

Programme language: FORTRAN
Programme available: yes
Written for computer type: ICL 1907

Name and Address: K. S. Swetlov
Soviet Union

References: 39

Equation used for

- flow through cracks: 1D)
- flow through large openings: 2G)
- flow through duct work: 2G)
- fan flow characteristics: ?
- wind pressure: ?
- thermal buoyancy: ?
- outside pressure fluctuation: ?
- circulation flow on large openings: ?

Algorithm to solve the nonlinear set of equations

- name of algorithm: Newton
- equation: ?

Maximal number of rooms: 150
(including shafts, corridors, etc.)

Limits on number of

- openings per room: ?
- shafts, corridors, floors: ?
- mechanical ventilation systems: ?

Programme language: ?

Programme available: ?

Written for computer type: ?

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

*LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*