Air Infiltration Review

a quarterly newsletter from the IEA Air Infiltration and Ventilation Centre

International Energy Agency - AIVC Vol. 15, No. 1, December 1993

Energy Impact of Ventilation and Air Infiltration - 14th AIVC Conference

21 - 23 September 1993, Industriens Hus Conference Centre, Copenhagen, Denmark.

By Mark J Limb, Air Infiltration and Ventilation Centre.

The theme of the 14th Air Infiltration and Ventilation Centre's annual conference focused on the energy impact of ventilation. In total, fifty six papers were presented over three days, addressing the importance of ventilation as an energy user. The Keynote presentation was given by Professor Ole Fanger from The Technical University of Denmark in which he encapsulated the essence of the conference. His presentation discussed two questions "Why do we ventilate ?" and "Why do we want to conserve energy?". He also outlined European efforts to gather data on pollution sources within buildings, for the European IAQ Audit Project and for the proposed EC European database of indoor air pollutant sources in buildings.

The first session on ventilation and energy continued the theme of the keynote presentation. Johnny Kronvall from Technergo, Sweden reported on the results from the ventilation and airtightness measurements in Swedish dwellings as part of the 1992 Swedish Energy and Indoor Climate Survey (the ELIB-Study). Ventilation and air leakage rates were measured from 1200 randomly selected single and multi-family Swedish dwellings. By considering the age, construction year, ventilation system, renovation status and geographical location the study confirmed that newer houses were more airtight than older houses. The study also showed the prescribed n_{50} leakage value stated by the Swedish Building Code is only reached by the newest multifamily houses.

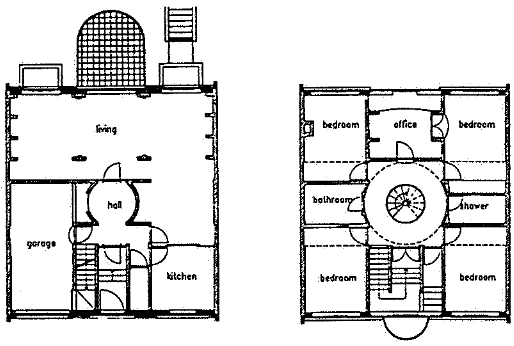
Max Sherman from the Lawrence Berkeley Laboratory then described a US evaluation of the energy impact of ventilation in housing study. The study also attempted to estimate the energy savings or penalties associated with tightening or loosening the building envelope. The study provides estimates for heating and cooling energy use of three cases to satisfy ASHRAE standard 62, 119 and a base case composed of a "best estimate" of the US housing stock. Max reported that the average annual ventilation energy use for a typical dwelling is about 46GJ (about 50% of the total energy use); the cost effective savings potential is about 28GJ. The associated total annual ventilation energy use for the residential stock is about 3 EJ (ExaJoules).

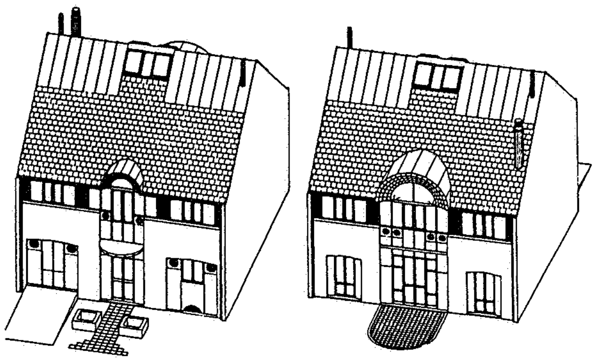
In this issue

Combined cooling and displacement systems generated much attention with three authors presenting work on this subject. During the first of the three poster sessions Claude Alain-Roulet, from LESO EPFL Switzerland examined the interaction between cooling ceilings and displacement ventilation, to determine the performance of the system in supplying fresh air and removing contaminants from a room. Using ventilation efficiency measurements they found that displacement systems work well when the cooling ceiling is either off or on, if the specific air flow rate is high (3.3/h). The cooling ceiling counteracts the upward displacement ventilation and induces partial mixing.

Markus Koschenz from EMPA, Switzerland then described research to simulate displacement ventilation and radiative cooling, using a new more detailed TRNSYS-Type model. This adaptation simulates the temperature gradient in the room with 3 air nodes. Different cooling ceiling systems combined with ventilation systems, especially displacement flow systems were then summarised by Gunter Mertz from FGK Germany.

Two papers were also presented on passive stack ventilation systems (PSV). Rodger Edwards from UMIST in the UK described a joint project that compared mechanical ventilation with heat recovery with PSV systems for UK dwellings. This study found that PSV with humidity sensitive extract offered increased potential for energy saving, but should only be used where humidity is the main pollutant. John Palmer from Databuild in the UK described an interesting case study of a PSV system installed in a infant's school.





Ground plans and front and rear facade of PLEIADE dwelling

The next two sessions developed the themes of ventilation energy and indoor air quality, while some focused mainly on energy. For example, Peter Wouters from the Belgian Building Research Institute outlined a new project "The PLEIADE (Passive and Low Energy Innovative Architecture DEsign) Dwelling" as part of IEA Annex XIII "Advanced Low Energy Housing". While David Lorenzetti from the Massachusetts Institute of Technology (MIT), USA described an interesting study in which analytic expressions where developed for power and pressure in a centrifugal fan. They may be expected to represent the behaviour of the fan more accurately than the fan laws.

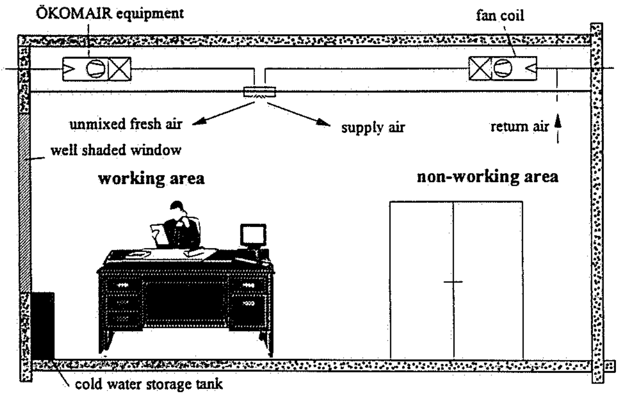
Other energy related studies include Jean Villenave from CSTB, France who outlined the common ventilation systems used in France. He stressed that an essential element was that systems are assessed by their performance and that French systems were measured with regard to heat loss. Bela Barath from Ingenieurburo Barath and Wagner GmbH, Germany outlined "ÖKOMAIR", a new ventilation and cooling system in which return air is cooled by fan coils and outside air is provided directly to the space and cooled by cold water storage, during the night.

Air
Infiltration
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.



Ökomair: sketch of office room

While Jorma Heikkinen from the Technical Research Centre of Finland described a number of projects under long term investigation to study the performance of residential ventilation systems in Finland. Two conclusions of this study were that the normal maintenance work was not sufficient to keep the ventilation and heating system in planned condition in the long term, and that the energy saving devices installed into the demonstration houses do work.

On the theme of indoor air quality issues, Marco Perino of the Politecnico di Torino discussed a joint project with Italgas on the influence of purpose provided openings on air changes and indoor air quality of buildings equipped with gas fired appliances. The study confirmed the importance of chimney cross section, height and shape in achieving safe operation.

A number of papers outlined research that combined the energy and indoor air quality issues of ventilation. Marie Hult from The City of Stockholm, Sweden for example described the programme for energy efficient and healthy apartment buildings in Stockholm. The results of a two year follow up period comparing houses built to the specifications of this programme with those built in the eighties, indicated the programme represents a reduction in energy consumption of some 35% and thus a corresponding reduction in environmentally hazardous effluent.

A new feature for the total heat recovery wheel was outlined by Frank Dehli of the University of Stuttgart, Germany. A common problem with these devices has been cross contamination of odours from exhaust air to supply air. This paper describes a new desiccant which has been developed to prevent such cross contamination without decreasing the latent energy recovery efficiency. While an interesting study was outlined by Lars Goran Månsson of LGM Consult AB, Sweden in which the influence of indoor tobacco smoking on energy demand for ventilation was examined. The study estimated that the extra energy demand for ventilation caused by indoor smoking in non-domestic buildings outside industry production is at least about 3700 million ECU (4000 million US$) annually in the 14 AIVC countries.

Measurement techniques were the topic of session five with ten poster presentations. The use of tracer gas techniques, modelling and simulations, thermography and visualisation techniques were all described.

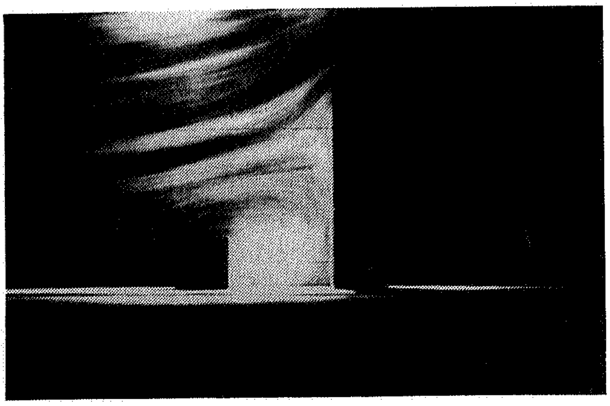
Nils Breum from the National Institute of Occupational Health in Denmark compared mixing ventilation systems (MIXVENT) with displacement systems (DISVENT) for use in industry using tracer gas studies. Using the approach of intervention at a factory the performance of MIXVENT was compared to DISPVENT in terms of air renewal. Displacement ventilation improved air exchange efficiency at room level, as well as at workstation level. The overall conclusion of this study was that displacement ventilation had the potential for improving environmental conditions in industry.

Corine Brouns from the Coventry University in the UK, described a multizone laboratory model for the testing and validation of tracer gas measurement techniques. The facility is composed of four interconnected zones, with the flow down each path monitored by a flow meter. The model can be used to validate tracer gas measurement techniques for the extraction of inter zone flows and for the determination of ventilation effectiveness parameters. The paper gives a number of examples of comparisons between a number of different tracer gas injection strategies. An important conclusion of this work is that the overall air change rate is found most reliable from the steady state decay curve.

The final oral presentation contained five papers and concentrated on ventilation modelling and simulation. Anker Nielsen from the Narvik Institute of Technology, Norway described measurements of air change and energy loss with large open outer doors. The results of tracer gas and theoretical analysis were compared to find the size of gravity driven flow air change from open doors. A conclusion was that further research into the potential energy savings from the use of air locks in such situations should be examined.

Jim Reardon, from NRC, Canada described a recent research project in which weather conditions and envelope pressures were measured in a two storey house, in order to observe the movements in the neutral pressure level. The subsequent statistical analysis has provided valuable data for both researchers and designers alike.

Earl Perera from the Building Research Establishment in the UK presented the results of a study examining the proximity effects of a taller building near a smaller one on ventilation and space heating loss. A multizone prediction program was used to determine the infiltration through the envelope and ventilation through purpose provided openings. Wind tunnel investigations provided the necessary wind pressure data. Ventilation rates of the low building can be reduced by as much as 35% for winds blowing normal to the front face with a tall building in close proximity. Average ventilation rates expected during the heating season can be reduced by 15% if it is an open site and by 10% if sheltered.



Typical airflow around model of tall building

The conference was summed up by David Harrje from the USA who suggested that the theme of the conference presented an apparent conflict between ventilation to ensure good indoor air quality on the one hand whilst on the other restricting ventilation heat loss to save energy. David also noted the emergence of new techniques and the variety of different buildings under investigation. Not only are pressurisation and tracer gas techniques being used, but thermography, and more powerful computer models and simulation programs such as cfd. Dwellings have also generated much research interest, but other types of buildings such as swimming pools, atria, schools, auditoria and clean rooms are also generating much interest. Work to combine the indoor air quality concerns with the energy issues such as the heat recovery wheels and tobacco smoke studies were encouraging, and courtyard air flow studies set the tone of future conferences. Awards for best paper and poster went to Max Sherman and Corine Brouns, whose contributions are featured in this newsletter.

SSB '94: 4th International Conference on System Simulation in Buildings

University of Liège, December 5-7, 1994

The following topics will be considered:

- Building and HVAC component modelling;
- Parameter identification;
- Experimental validation;
- Use of models for system design optimal control, fault detection and diagnosis;
- Case Studies

Contact: Dr Jean Lebrun, Laboratoire de Thermodynamique, Université de Liège, Sart-Tilman Bâtiment B49, B-4000 Liège, Belgium, Fax: +32 41 56 48 12

A Four Zone Ventilation Test Facility

Award winning poster from the 14th AIVC Conference
by C E Brouns and J R Waters, Coventry University (UK)

1 MULTIZONE TEST FACILITY

Objectives

Construction of a multizone test facility for the testing and validation of measurement techniques, with particular emphasis on the effect of:-

(i) Different interzone flow patterns;
(ii) Different injection strategies;
(iii) Different methods of analysis;
(iv) Increasing number of zones

Conclusions

To date, a range of different flow patterns, injection strategies and methods of solution have been investigated using the multizone test facility with two, three and four zone configurations. It is found to be a successful tool for testing and validating methods of measurement.

Basic Design Details

Number of Zones: 4
Size of Each Zone: 1 m^3
Range of Flow Rates: 0-40 l/min in each flow path
Time Constant of System: Normally in the range 30 to 90 min

Flows driven by Diaphragm Pumps
Flows measured by in-line Rotameters

Tracer gas used : SF_6
Tracer Measurements: 6 Independent Analyser Units (1 per zone, 1 on inlet and 1 on outlet).

Calibrations

Leakage Testing of Zones in Test Facility: ≤ 0.04 l/min at 50 mm H_2O pressure differential.

Rotameters:

(i) Manufacturers' specifications:

± 2.50 % of Full Scale Deflection for low flow rates.
± 1.25 % of Full Scale Deflection for high flow rates.

(ii) Laboratory Calibrations:

± 2.00 % of Full Scale Deflection for low flow rates.
± 1.00 % of Full Scale Deflection for high flow rates.

Tracer gas concentration measurements:
Detectors linear to within 1%.

Temperature 20° C ± 2° C.

Injection Strategies

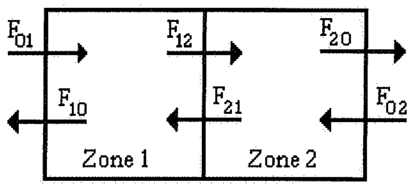
1. In principle, any Injection Strategy can be used.

2. Injection Patterns tested to date:

    (i) Decay.
    (ii) Step-up.
    (iii) Multiple Step-Up.
    (iv) Multiple Pulse.

2 DETAILS OF MEASUREMENTS TO DATE

Schedule of Measurements: Two Zone Model

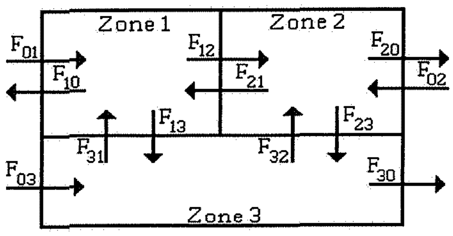


Schematic Diagram of the Two Zone Model

Test No 2z..	Ventilation flow rate (l/min)						Comments
	F_{01}	F_{02}	F_{10}	F_{12}	F_{20}	F_{21}	
01,02,03	20	20	10	10	30	0	Special case, $F_{01}=F_{02}$
04,05	30	10	20	10	20	0	Special case, $F_{10}=F_{20}$
06,07	30	15	15	15	30	0	Special case, $S_1=S_2$
08,09	30	0	10	20	20	0	General case
10	20	10	15	5	15	0	General case
11,12	30	15	20	20	25	10	General case

Description of the Flow Patterns Selected for the Two Zone Model

Schedule of Measurements: Three Zone Model

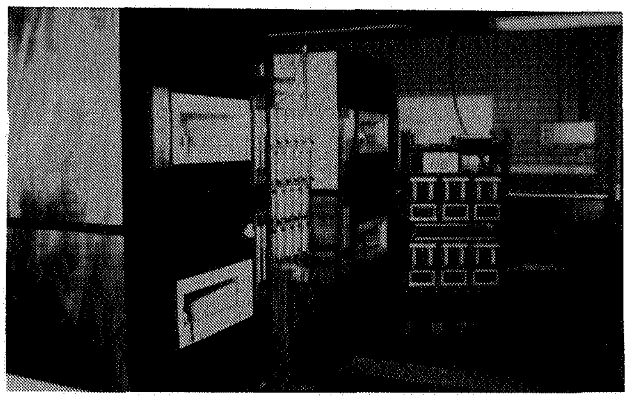


Schematic Diagram of the Three Zone Model

Test 3z..	Ventilation Flow Rates, F_{ij} (l/min)								
	F_{01}	F_{02}	F_{03}	F_{10}	F_{12}	F_{13}	F_{20}	F_{21}	F_{23}
01-14	25	25	25	25	15	0	20	0	20
15-17	25	20	15	20	15	0	20	0	15
18-19	20	15	10	15	10	5	10	5	15
20	25	0	15	10	20	0	15	0	15
21	25	15	20	15	10	5	20	5	10

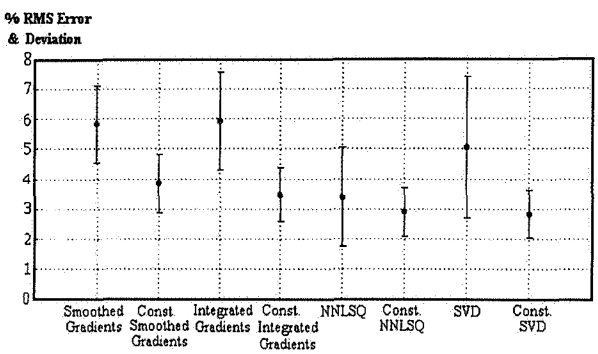
Test 3z..	F_{ij} (l/min)			Comments
	F_{30}	F_{31}	F_{32}	
01-14	30	15	0	Special case, $F_{01}=F_{02}=F_{03}$
15-17	20	10	0	Special case, $F_{10}=F_{20}=F_{30}$
18-19	20	5	5	Special case, $S_1=S_2=S_3$
20	15	5	10	Special case, $S_1=S_2=S_3$
21	25	0	10	General case

Description of the Flow Patterns Selected for the Three Zone Model

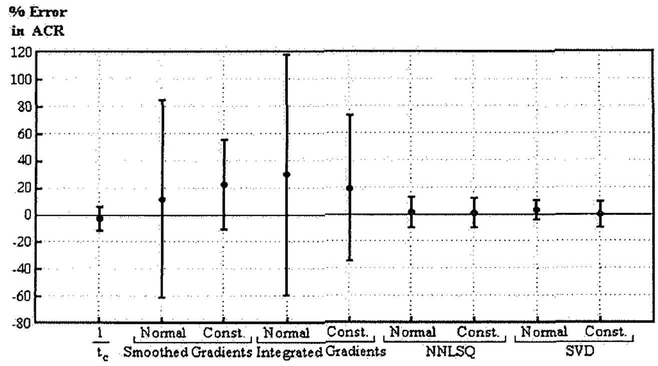


3 EXAMPLE OUTPUT FROM EXPERIMENTS TO DATE

Typical Results: Two Zone Model

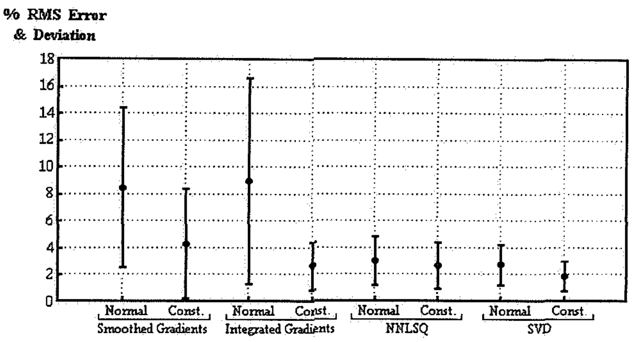


%RMS Error and Standard Deviation versus Method of Solution

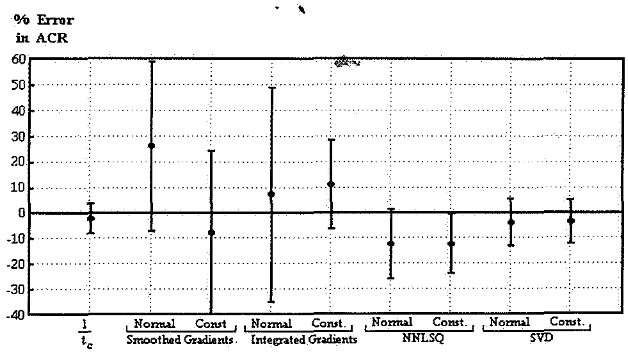


% Error in ACR estimated from measured data sets

Typical Results: Three Zone Model

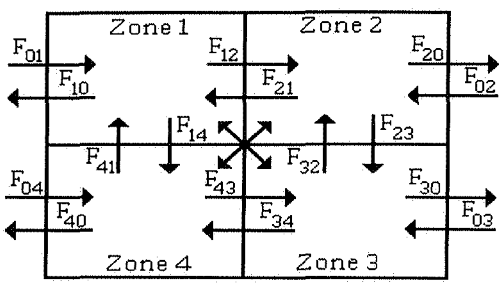


% RMS Error and Standard Deviation versus Method of Solution



% Error in ACR estimated from measured data sets

Schedule of Measurements: Four Zone Model



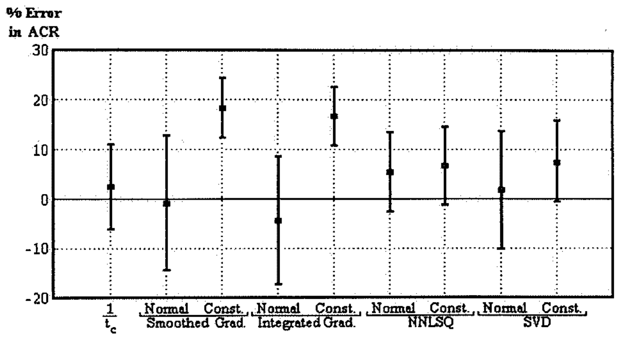
Schematic Diagram of the Four Zone Model

4z..	F_{01}	F_{02}	F_{03}	F_{04}	F_{10}	F_{12}	F_{13}	F_{14}	F_{20}	F_{21}	F_{23}	F_{2}
	Ventilation Flow Rates (l/min)											
1-2	15	15	15	15	10	15	0	0	20	5	10	0
3-5	18	8	15	7	12	15	0	0	12	4	12	0
6	20	15	10	8	10	15	0	10	10	10	15	0

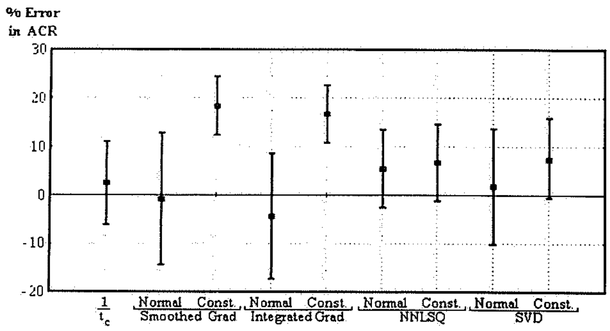
4z..	F_{30}	F_{31}	F_{32}	F_{34}	F_{40}	F_{41}	F_{42}	F_{43}	Comments
	Ventilation Flow Rates (l/min)								
1-2	10	0	5	15	20	5	0	5	$F_{01}=F_{02}=F_{03}=F_{04}$
3-5	12	0	5	15	12	5	0	5	$F_{10}=F_{20}=F_{30}=F_{40}$
6	13	0	5	17	20	5	0	10	$S_1=S_2=S_3=S_4$

Description of the Flow Patterns Selected for the Four Zone Model

Typical Results: Four Zone Model

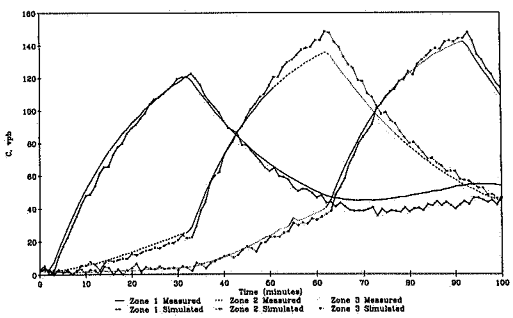


% RMS Error and Standard Deviation versus Method of Solution

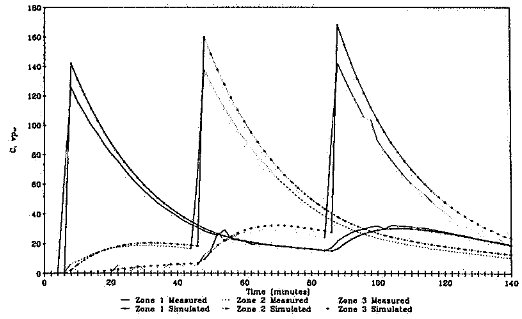


% Error in ACR estimated from measured data sets

4 COMPARISON WITH 0% APPLIED RANDOM ERROR

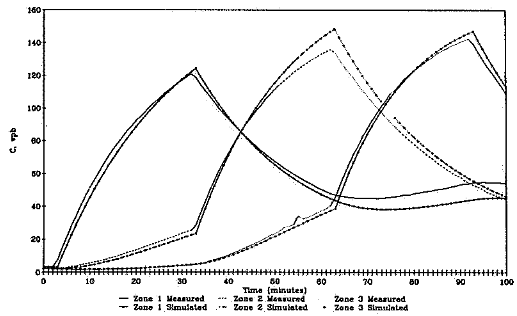


Tracer Gas Concentration Curves: Data Set 3Z08

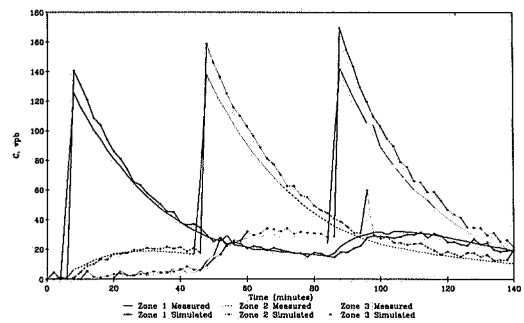


Tracer Gas Concentration Curves: Data Set 3Z14

5 COMPARISON WITH 1% APPLIED RANDOM ERROR



Tracer Gas Concentration Curves: Data Set 3Z08 (1% Random Error)



Tracer Gas Concentration Curves: Date Set 3Z14 (1% Random Error)

Ventilation-Energy Liabilities In U.S. Dwellings

Award winning paper from the 14th AIVC Conference
by Max Sherman and Nance Matson,
Energy Performance of Buildings Group, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California, USA

Abstract

Existing dwellings in the United States are ventilated primarily through leaks in the building shell (i.e., infiltration) rather than by mechanical ventilation systems. The purpose of this report is to ascertain, from best available data, the energy liability associated with providing the current levels of ventilation and to estimate the energy savings or penalties associated with tightening or loosening the building envelope. Based on this analysis, the average annual ventilation energy use for a typical dwelling is about 46 GJ (roughly 50% of total energy usage); the cost-effective savings potential is about 28 GJ. The associated total annual ventilation energy use for the residential stock is about 3 EJ (ExaJoules).

List Of Symbols

A_f	building floor area [m^2]
ACH	effective air change rate (ach) [h^{-1}]
E	annual energy load [kJ]
IDD	infiltration degree days [°C-day]
N	number of hours [h]
NL	normalized leakage area [-]
s	specific infiltration [m/s]
s_o	average specific infiltration [0.71 m/s]
w	air change rate factor accounting for effect of local weather (ACH) [$^{-h}$]
ρ	density of air [1.2 kg/m^3]
[h]	indicates hourly value

Introduction

Infiltration and ventilation in dwellings is conventionally believed to account for 1/3 to 1/2 of the space conditioning energy. However, there is not a great deal of measurement data or analysis to substantiate this assumption. The purpose of this project [11] is to use existing data to estimate the energy and ventilation liabilities in the current U.S. housing stock as well as scenarios based on energy conservation and ventilation strategies. The LBL infiltration model[10] and its derivatives will be used as the basis for the calculation.

Methodology

In order to model each of the almost 75 million single-family households in the U.S. would require more data and manpower resources than currently exist. The approach we use instead, is to take the sources of data available and combine them at an appropriate level of detail using database management tools.

Putting all of the data sources together we can determine for each county the number of houses (from the U.S. Census [6]), the type and sizes of houses (from the Residential Energy Consumption Survey, RECS[13]), the leakage properties (from the AIVC Leakage Database[8]) and the representative weather conditions.[2,7]

We developed 32 different types of houses: old vs. new (using 1970 as a dividing point); single-story vs. multistory; poor condition vs. go od condition; duct systems vs. none; and floor leakage vs. no floor leakage. The RECS data is used to determine, for each of the nine census divisions, the average floor area, percentage of air conditioning use and number of houses for each of the 32 house types. The AIVC leakage data is used to determine representative leakage data for each house type. Every county within a given division is assumed to have the same relative distribution of housetypes, where the number of houses in each county is determined from the Census data and is the total of the number of single-family detached, single-family attached and mobile home dwellings. For each county, the most representative U.S. weather sites is used based primarily on geography.

The fundamental relationship between the infiltration and the house and climate properties is expressed by the LBL infiltration model[12], wh ich is incorporated into the ASHRAE Handbook of Fundamentals[1]. The LBL infiltration model is used to generate, on an hourly basis, specific infiltration and air flow rates. From these hourly results, seasonal average air change rates and corresponding energy consumption, as well as overall measures of tightness (ASHRAE Standard 119)[4] and rates for adequate ventilation (ASHRAE Standard 62)[3] are determined.

The effective air change rate is calculated by a process similar to that used in ASHRAE Standard 136-935:

$$ACH = 1.44 . w . NL \qquad \text{(EQ 1)}$$

The total number of heating and cooling Infiltration degree days (IDD)[13] is a good estimate of the energy intensity of the climate with respect to infiltration. The annual energy intensity, reflecting heating and cooling energy consumption, can be calculated from the normalized leakage and the number of infiltration degree days:

$$E/(A_f) = 86.4 \,.\, s_o \,.\, \rho C_p \,.\, NL \,.\, IDD \qquad \text{(EQ 2)}$$

where the coefficient 86.4 has the units of s/day. Ventilation mode, as modeled with natural ventilation, does not carry any energy liabilities.

Compliance is checked with two ASHRAE standards: Standard 1194, the tightness standard, and Standard 623, the ventilation standard.

ASHRAE Standard 119 relates normalized leakage to infiltration degree-days. The standard can be expressed[9] in the following form:

$$NL = \leq \frac{200}{IDD} \qquad \text{(EQ 3)}$$

where the denominator is the total number of IDDs for heating and cooling. A building is considered to be in compliance with the tightness standard when the above relationship is true.

The effective air change rate, as calculated using Equation 1, is the value of the air change rate that should be used in determining compliance with minimum ventilation requirements. ASHRAE Standard 62 sets minimum air change rate requirements, for residences, of 0.35 air changes per hour. If we use Equation 1 to represent the effective minimum air change rate then the requirement becomes:

$$w \,.\, NL \geq 0.24 \qquad \text{(EQ 4)}$$

Results

The houses used in this analysis are selected to reflect the current U.S. single family housing stock, including almost 75 million households (86% of the total U.S. residential housing floor area). Normalized leakage factors (NL) range from 0.24 to 1.70 for the 32 housetypes. Shielding and terrain classes of III are assumed for all locations.

The scenario described above can be considered as the base case in that it represents our best estimate of the housing stock. The same approach is used to consider two alternative scenarios: the "119 Case" and the "62 Case". For the "119 Case," any houses that do not meet the tightness standard are tightened to meet the standard.

Conversely, for the "62 Case," any houses that do not meet the ventilation standard are loosened unit they meet the standard.

Using the characteristics of the housing stock described above, for each of the three scenarios, we have derived corresponding infiltration energy consumption, ventilation rates and percent of houses complying with ASHRAE standards 119 and 62. The results from our three scenarios follow:

Air Change Rates and ASHRAE Standards

Our results would indicate that the national average effective annual air change rate is 0.83 ACH with a 19% standard deviation, based on county-averaged air change rates. Of real importance, however, is the compliance with the tightness and ventilation standards, Standards 119 and 62 respectively. Table 1, "Percent of U.S. Houses Meeting ASHRAE Standards," shows the percentages of houses which comply with these Standards

TABLE 1. Percent of U.S. Houses Meeting ASHRAE Standards Standard % of Houses

Standard	% of houses	
Standard 62 only	50.2	88% Meet 62
Both Standards	37.6	
Standard 119 only	12.1	50% Meet 119
Neither Standard	0.1	

Due to the looseness of the U.S. housing stock, 88% of the base case houses meet Standard 62, the standard for adequate ventilation. Conversely, 50% of the houses meet Standard 119, the tightness standard. Of interest is the 38% of houses which meet both standards, implying that some balance between lower energy consumption and increased indoor air quality has been achieved for certain climates. Only a small portion of houses meet neither standard, being too loose to meet the tightness standard but not loose enough to meet the ventilation standard.

After the houses in the base case are tightened to meet Standard 119, the tightness standard, the national average effective annual air change rate is smaller than that of the base case, at 0.34 ACH with a 20% standard deviation. As most of the houses are quite loose and have to be tightened to meet Standard 119, he percentage of houses which meet Standard 62 drops from 88% to 49%.

After the houses in the base case are loosened to meet Standard 62, the ventilation standard, the national average effective annual air cha nge rates is slightly higher than that of the base case, at 0.87 ACH with a standard deviation of 16%. As most of the houses in the base case already meet Standard 62, the corresponding percentage of houses that meet Standard 119 drops slightly from 50% to 47%.

Energy Consumption

Table 2 summarizes, on a national basis, annual heating, cooling and total infiltration energy consumption for the base case and each of the two scenarios. By tightening up the housing stock to meet Standard 119, the potential national energy savings are projected to be up to 2.1 EJ/Year (28 GJ/house/year). However, at the same time, the number of houses which meet the ventilation standard drop from 88% to 49%. The converse case, loosening the housing stock to meet Standard 62, results in a potential national increase in energy consumption of 0.1 EJ/Year (1.3 GJ/house/year).

Table 2: Annual Infiltration Energy - US Single Family Houses

Scenario	Heating (EJ/Year)	Cooling (EJ/Year)	Total (EJ/Year)
Base Case	3.0	0.4	3.4
119 Case	1.1	0.2	1.3
62 Case	3.1	0.4	3.5

Conclusions

Our analysis is based on housing and leakage data available on hand at the time of our analysis. This analysis provides a preliminary view of the distribution and magnitude of infiltration-related energy consumption in the U.S. single- family building sector. We have found that, based on our analysis, the current U.S. housing stock is relatively loose, with 88% of the houses meeting ASHRAE Standard 62.

From an indoor air quality perspective, it is tempting to propose that existing houses should be loosened to meet Standard 62. From an energy perspective, however, knowing that it is possible to save up to 28 GJ/house/year by tightening the houses, it suggests that another tack be taken. For much of the country, strategies such as mechanical ventilation and heat recovery, could be utilized to create a middle ground and insure maximizing energy savings as well as providing adequate ventilation.

The 2 EJ potential infiltration savings cannot be tapped without accounting for the addition of mechanical ventilation systems in some climates. A true economic analysis requires fuel prices, heat recovery option efficiencies as well as the standard economic data requirements. The huge potential savings, however, justifies an increased emphasis on residential ventilation.

Although the efforts reported here have begun to address the problem, it is only a beginning. The level of detail in key databases and the range of options considered are somewhat limited. Future work will focus on three main issues: the leakage database, evaluation of mechanical ventilation options and expansion to include analysis of the multifamily building sector. A request for U.S. single-family leakage data is being circulated to practitioners and researchers, with responses currently being received at LBL.

Acknowledgements

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technology of the U.S. Department of Energy under contract no. DE-AC03-76SF0098.

References

1. ASHRAE Handbook of Fundamentals, Chapter 23, American Society of Heating, Refrigerating and Air conditioning Engineers 1989.
2. ASHRAE Handbook of Fundamentals, Chapter 24, American Society of Heating, Refrigerating and Air conditioning Engineers 1989
3. ASHRAE Standard 62, Air Leakage Performance for Detached Single-Family Residential Buildings, American Society of Heating, Refrigerating and Air conditioning Engineers, 1989.
4. ASHRAE Standard 119, Air Leakage Performance for Detached Single-Family Residential Buildings, American Society of Heating, Refrigerating and Air conditioning Engineers, 1988.
5. ASHRAE Standard 136, A Method of Determining Air Change Rates in Detached Dwellings, American Society of Heating, Refrigerating and Air conditioning Engineers, 1993.
6. Bureau of the Census, U.S. Department of Commerce, "21st Decennial Census," 1990.
7. California Energy Commission, "Climate Zone Weather Data Analysis and Revision Project," April 1991.
8. M. Limb, "AIRGUIDE: Guide to the AIVC's Bibliographic Database," Air Infiltration and Ventilation Centre, AIC-TN-38-1992, 1992.
9. M.H. Sherman, "EXEGESIS OF PROPOSED ASHRAE STANDARD 119: Air Leakage Performance for Detached Single-Family Residential Buildings." Proc. BTECC/DOE Symposium on Guidelines for Air Infiltration, Ventilation, and Moisture Transfer, Fort Worth, TX, December 2-4, 1986. Lawrence Berkeley Laboratory Report No. LBL-21040, July 1986.
10. M.H. Sherman, D.T. Grimsrud, "The Measurement of Infiltration using Fan Pressurization and Weather Data" Proceedings, First International Air Infiltration Centre Conference, London, England. Lawrence Berkeley Laboratory Report, LBL-10852, October 1980.
11. M.H. Sherman, N.E. Matson, "Ventilation-Energy Liabilities in U.S. Dwellings." AIVC, Copenhagen, Denmark, 1993. Lawrence Berkeley Laboratory Report, LBL-33890.
12. M.H. Sherman, M.P. Modera, "Infiltration Using the LBL Infiltration Model." Special Technical Publication No. 904, Measured Air Leakage Performance of Buildings, pp. 325 - 347. ASTM, Philadelphia, PA, 1984; Lawrence Berkeley Laboratory
13. U.S.D.O.E., Energy Information Administration, "Housing Characteristics: Residential Energy Consumption Survey, 1990." DOE/EIA-0314(90), May, 1992

AIVC Survey of Research 1994

The AIVC Survey of Research 1994 is now underway. Questionnaires (enclosed with this newsletter) should be returned to the AIVC as soon as possible. We take this opportunity to thank you for your contributions.

Ventilation and Infiltration Characteristics of Lift Shafts and Stair Wells - A Selected Bibliography

Adapted from an AIVC Literature List by Mark Limb, Scientist, AIVC

1. Introduction

The stack effect provides the driving force for vertical air movement within buildings. Its effects are especially pronounced in high rise developments, where the air leakage associated with elevators, stairs and service shafts can be a major concern. Stairwells and lift shafts themselves provide occupant access to those floors above or below ground level as well as providing routes for the movement of air. A knowledge therefore of the air movement characteristics of such shafts is vital in understanding the ventilation and leakage patterns in medium and high rise buildings. Such work has been particularly helpful in the predication and evaluation of smoke control procedures.

This review attempts to outline the main areas of research that have been undertaken in the evaluation and understanding of air leakage characteristics of both stairwells and lift shafts.

2. Ventilation of stair wells

Air driven by stack and wind pressures cause vertical air movement between floors, through corridors and vertical shafts. Such air movement has serious comfort, energy and indoor air quality implications, and much work has been undertaken in order to understand and model these air movements. These are briefly outlined below.

2.1 Air movement and infiltration

A number of studies restrict their work to the movement of air within stairwells only. Such work investigates the buoyancy driven recirculating flows in stairwells and their associated energy transfer, usually between two or more zones. This includes Reynolds et al (1986, #2959), Riffat et al (#3131), Zohrabian et al (#3583), Balcomb and Yamaguchi (#3826), Jones and Balcomb (#3835), van der Maas and Roulet (#4680), Edwards and Irwin (#4845), and Ergin-Ozkan et al (#6029). The main aim of these investigations is to develop mathematical and theoretical procedures to model thermal air movements, in what can be a rather complex geometrical confined.

Several investigations on the other hand, deal with the combined stack and wind pressure effects on tall buildings and their associated infiltration and pressure effects these include studies by Maszczynski (#50), Karulak (#121), Zuercher and Feustal (#1255), and Achakji and Tamura (#3906). One such study attempt to predict infiltration rates in high rise buildings. In order to use air flow calculations to estimate possible energy savings from reductions in infiltration actual pressure distributions along the building facade is needed. Zuercher and Feustal (#1255) argue that local pressure coefficients can only be obtained from wind tunnel experiments, where the wind velocity profile as well as the surrounding building pattern matches the real situation as close as possible.

A study by Karulak (#121) focuses on the overall nature of infiltration and air movement in multi-storey buildings. In conclusion the author identifies the significance of the vertical temperature flows and states that proper design of mechanical ventilation systems is essential. The unsteadiness of balanced systems in tall buildings can be exploited by the stack effect, resulting in large amounts of vertical heat transfer. This conclusion is echoed in a study by Rydberg (#1489) which examines disturbances in ventilation systems. In tall buildings stack pressures can often override the ventilation system causing the system to fail.

2.2 Air heat and moisture transfer

A number of studies investigating the nature of air, heat and moisture transfer throughout a building have identified stairwells as a major route of transfer. These include Tamura and Wilson (#140), Railio (#784), Rydberg (#1489), Jun and Sheung (#2712), Bahac (#2880), Vitstrom (#3893), Shaw et al (#5125, #5265). Pressurisation and tracer gas studies have been used in these investigations, to test the leakage characteristics of individual rooms and stairwells. Under certain conditions these studies have found that the stack effect in medium and high rise buildings plays a vital role in air and heat transport. These flows can be minimised according to Tamura (#140) by providing supply air in excess of the exhaust, ie by pressurising the stairwell area. However a number of problems are associated with positive pressure buildings including possible condensation damage.

Another area of focus has been the pollutant transportational capabilities of air movement within the stairwell. The migration of moisture from the ground to first floor in a two-story dwelling has been studied by Edwards and Irwin (#4845) and micro-organism migration in hospitals via stairwell air flows by Munch et al (#2360) are two examples. A more generalised investigation (Grot et al (#3609) concerns the indoor air quality in a modern high rise office building. This study considered the spread of a number of pollutants including carbon dioxide, carbon monoxide and radon by lift and stairwell are flows. All three of these investigations demonstrate the significance of the stack effect, with higher concentrations of moisture, office and hospital pollutants and micro-organisms in the air circulating around the upper floors of the building.

2.3 Smoke control and fire safety

The effects of air flows within stairwells has generated much interest especially in the area of smoke control and fire safety; Tamura (#2057, #2058, #4560, #5145, #5633), Ostatek et al (#2527), Klote (#3459, #3904), Said and MacDonald (#5123). Klote #3904 has identified two control measures which are currently used to limit the spread of fire and smoke out of the building. Zoned control is where a building is divided into a number of smoke zones, each separated from the others by partitions and floors. In the event of a fire pressure differences and airflows produced by mechanical fans can be used to limit the spread of fire and smoke.

However the main control mechanism is to pressurise the stairwell itself, several papers discuss such pressurisation systems these include Tamura and Shaw (#299), Klote (#3459), Clark and Harris (#3376), Grot et al (#3906), Chow et al (#5582), Mung (#5589), McNemar J (1975), and Shaw and Tamura (1976). The aim of such systems is to ensure that stairwells can act as escape routes in the case of a fire. The stairwell is pressurised by the injection of outdoor air into the shaft so that the direction of air flow is from the shaft to its surroundings. ASHRAE have identified two pressurisation systems, single and multiple injection systems (ASHRAE, 1987).

Klote (#3904) has identified three major design considerations with these systems. The consequences of stack and wind pressures acting over the height of the building are that under times of excessive pressure differences doors joining the floor corridor and stairwell may stick (Tamblyn 1991). Stair pressurisation systems should be able to reduce the loss of pressure resulting from several stair doors being open simultaneously, while remaining to operate effectively. A final consideration is the location of the supply air inlets and fans.

Attempts to overcome these design problems have led to many investigations including Tamura (#4560, #5145) and to the specification of a variety of codes and standards. These govern air velocities at door openings and specify the required amount of minimum and maximum pressurization. Other papers including Tamura (#5633) recommend that the stair pressurization system should operate together with a mechanical exhaust fan to vent the fire floor. The work done in this area includes theoretical, mathematical and real test investigations. Recently Computational Fluid Dynamics has been used to evaluate air flow and smoke movement in stairwells, such studies include Munch et al (#2360) and Ergin-Ozkan (#6029).

3. Ventilation of lift shafts

The ventilation and leakage characteristics of lift shafts are somewhat different to that of stairwells. Lifts shafts are usually located in the centre of the building and form part of its service core. They not only contain the lift car, but also many pipes, wires and ducts associated with the services of the building. Shafts are usually constructed of concrete and have totally impermeable walls, floors and ceilings. Openings are allowed to secure ventilation, and to act as vents for gases, smoke and fire. A motor room is typically located directly over the shaft and having vents to facilitate the necessary air movement required by the plant. These vents are not used for the removal of stale air extracted from the building.

Stack driven air movement through lift shafts in tall buildings can be responsible for a variety of pressure problems. An understanding of the stack effect and associated air movement characteristics is essential if designers are to overcome such problems. In response to this a number of studies have investigated the interaction between the pressure generated by the stack effect and the building.

Tamblyn (1991) investigated the size of the stack effect in a 40 story apartment building to demonstrate the importance of such pressure problems. The ability to locate the natural pressure level is emphasised since this can help direct air tightening investigations to the top or bottom of the building. In this study to locate the neutral pressure level smoke was blown against the elevator door. If the smoke lingers, the neutral pressure level will be at that floor, while on other floors the smoke will be blown back from the shaft or drawn into it. In conclusion the author notes that stack pressures can not only cause elevator door opening problems but also indoor air quality problems. These can be controlled within acceptable limits by understanding the problem and modifying the ventilation systems design. Solutions discussed in this study centre around alterations in HVAC design to regulate a lift shaft pressurisation system.

The effect of stack pressures on the operation of mechanical ventilation systems has been investigated by two other studies. Tamura (#140) attempted to measure the pressure differences for a nine story building as a result of the stack effect and ventilation system operation. Finding in conclusion that in order to reduce the pressure differences and infiltration of air at low levels it was necessary to provide supply air in excess of the exhaust. If excess air is supplied uniformly the authors state that there will be a corresponding increase in the pressure differences causing exfiltration at upper levels. However condensation problems may result. While Rydberg (#1489) concentrated on the possible disturbances that a ventilation system has to overcome in tall buildings. Including for example those caused by the interaction of lifts and stairwells with the operation of the ventilation system. In order to counteract such disturbances, changes in the ventilation system and building design are proposed.

The effects of the vertical air movement generated by stack pressures to transfer warm ventilation air throughout a building are discussed by Wallace, (1985). The study compares the leakage characteristics of two high rise buildings. It concludes that air and heat movement via vertical stairwells and lift shafts and the resulting air leakage and infiltration represents a major problem in many high rise buildings. As a result of these findings a number of retrofits have been undertaken on the two buildings examined, including blocking openings in shafts and sealing up leakage routes, although results of these actions is not presented.

A case study which examines the air movement potential of a number of contaminates from sub-floor garage spaces to higher levels is considered by Grot et al (#3609). The authors conclude that if vertical lift and stair shafts were isolated and the ventilation systems of the garage were changed then most problems of pollutant migration in this building would be alleviated.

It is essential that lift shafts do not contribute to the spread of fire throughout a building. A number of precautions are associated with the design of lift shafts to ensure they do not. For example lift shafts are designed to the fire resistance specification of individual countries or localities. The outer shaft and its doors also contribute to added fire protection. The problems of elevator and passenger safety when a fire breaks out have been outlined in a paper by Sumka (#3910).

Several studies deal with lift shafts and the associated effects of fire and smoke. These studies examine ways of controlling the spread of fire and smoke throughout the building by venting the lift shafts and corridors. There are two main preventative methods. Natural venting methods to control fire and smoke spread are examined by Tamura (#2058). The study assumes that smoke migration follows the air flow pattern, which in large multi story buildings is vertical. The provision of openings at the top and bottom of lift shafts this smoke migration can be controlled. Opening the vent at the top of a vertical shaft will raise the level of the neutral pressure plane, increasing air flow into the shaft and correspondingly the number of stories into which air flows from the shaft is reduced. However the author concludes by noting that top venting increases smoke contamination of the shaft and cannot therefore be used for shafts in which smoke contamination must be restricted, such as stairwells. Such a system could, however assist in the evacuation of smoke from the building. Bottom venting inhibits the flow of smoke into the shaft from adjacent contaminated places. However due to the difficulty in preventing smoke contamination a number of precautions are also discussed.

A more modern method is to mechanically pressurise both the lift shafts and associated corridors in the same way as stairwells. Such systems have been reviewed by Tamura and Shaw (#299), Klote (#3904), Tamura and Klote (#3908). However concern exists regarding the pressure fluctuations resulting from the opening and closing of elevator doors. Pressurisation systems therefore need to have variable supply rates with feed back control or relief dampers in the walls of the elevator shafts or surrounding corridors.

Another area of concern related to smoke and fire safety is the transient pressures produced when the elevators car moves in its shaft. This piston effect can pull smoke into normally pressurised areas. Such effects can be overcome by improved design, a theoretical analysis of the pressures involved are discussed by Klote and Tamura (#3909).

As systems become more advanced integrated ventilation and fire safety equipment is being installed. Such systems include HVAC control systems designed to work effectively with fire management and smoke control systems can now prove a cost effective and highly reliable total system approach to fire safety. These systems have been reviewed by Shavit (#3905).

4. Conclusions

This review has identified the importance of stairwell and lift shaft air flows in tall buildings. Of primary interest is the characteristics and mechanisms of such air flows for the prediction of heat moisture and pollutant transport throughout buildings. The restriction and control of smoke and fire in vertical stair wells and lift shafts has also generated much interest along with the associated effects of stack pressures and the resulting air leakage characteristics especially in tall buildings. The interaction of these concerns with ventilation systems has also been an area of focus. Most papers cited in this review deal with the fundamentals of airflows in stairwells and lift shafts. Many use models to predict these phenomena as well as experimental data from test and real buildings. These examples provide important background guidelines for further research.

5. References

5 (a). Stairwell References

#NO 50 Amount of heat needed to warm air infiltrating under action of wind.
Zapotrzeboivanie ciepla na ogrz anie powietza infittrujacego na skutek dzialania wiatru.
AUTHOR Maszczynski E.
BIBINF Ciep. Ogrz. Went. February 1972, 4, 2, 39-44, 3 diagrs, 1 tab, 8 refs. #DATE 01:02:1972 in Polish

#NO 121 Air exchange in multi-storey buildings

Wymiana poivietrza w budynkach wielokondygnacyjinych
AUTHOR Karulak J.
BIBINF Ciep. Ogrz. Went. March 1970 3/6 p81-85 = H.V.R.A. Translation no.216 price 1.55 pounds #DATE 01:03:1970 in Polish, English

#NO 140 Pressure differences for nine-storey building as a result of chimney effect and ventilation system operation.
AUTHOR Tamura G.T. Wilson A.G.
BIBINF ASHRAE trans vol 72 p180-189 #DATE 24:01:1966 in English #AIC 1257

#NO 299 Air leakage data for the design of elevator and stair shaft pressurization system.
AUTHOR Tamura G.T. Shaw C.Y.
BIBINF ASHRAE trans vol 82 part 2 p179-190 8 figs, 3 tabs, 8 refs. D.B.R. Paper No. 717 #DATE 01:06:1976 in English

#NO 547 Ventilation rates
AUTHOR Nakazawa Y. Narasaki M.
BIBINF Trans.SHASE 54(1) 27-32, 7 figs, 7 tabs #DATE 01:01:1980 in Japanese #AIC 1728

#NO 784 Heat recovery from the exhaust air in old apartment buildings.
Lammon talteenotto poistoilmasta vanhoissa asuinkerrostaloissa.
AUTHOR Railio J.
BIBINF LVI May 1981 no.5 p.49-52 3 tabs. 3 refs. #DATE 01:05:1981 in Finnish #AIC 426

#NO 1255 Air infiltration in high-rise buildings.
AUTHOR Zuercher C.H. Feustel H.
BIBINF 4th AIC Conference "Air infiltration reduction in existing buildings" Switzerland, 26-28 September 1983 p.9.1-9.17 14 figs. 1 tab. 17 refs. #DATE 26:09:1983 in English

#NO 1489 Disturbances in ventilation systems. Part 1 and Part 2
AUTHOR Rydberg J.
BIBINF Heat.Vent.Engr. May 1960, 483-485,489, June 1960, 541-547, 9 figs, 2 refs. #DATE 00:05:1960 in English #AIC 928A and

#NO 1800 Temperature- and wind-induced air flow patterns in a staircase. Computer modelling and experimental verification.
AUTHOR Feustel H, Zuercher Ch, Diamond R et al
BIBINF Energy and Buildings, 1985, Vol 8, p105-122. 15 figs, 3 tabs, 45 refs. #DATE 07:11:1984 in English

#NO 2057 Analysis of Smoke Shafts for Control of Smoke Movement in Buildings.
AUTHOR Tamura, G. T.
BIBINF research.loc = ottawa, canada; type = report; #date 28:06:1970; volume.title = ashrae trans.; volume.no = 76; pages = 290-297; report.no = 2163; publisher.name = ashrae; in english

#NO 2058 Natural Venting to Control Smoke Movement in Buildings Via Vertical Shafts
AUTHOR Tamura, G. T.; Wilson, A. G.;
bibinf research.loc = ottawa, canada; type = report; #date 01:07:1970; volume.title = ashrae trans.; volume.no = 76; pages = 279-289; report.no = 2162; publisher.name = ashrae; in english

#NO 2360 Flow of microorganisms in a hospital stair shaft - full-scale measurements and mathematical model.
AUTHOR Munch W, Ruden H, et al.
BIBINF Energy Bldgs, Vol 9, No 3, 1986, p253-262, 8 figs, 14 refs. #DATE 00:08:1985 in English

#NO 2527 Air movement in buildings: computer programs calculating air pressures and air flows in buildings in which a fire is simulated.
AUTHOR Ostatek E, Phaff J C, De Gids W F
BIBINF IG-TNO/Dept GLB, Report No C411, February 1978, 27p, 2 refs. #DATE 00:02:1978 in English

#NO 2712 The effective and ineffective heat loss by infiltration - field measurement in a dormitory.
AUTHOR Guo Jun, Liu Ming Sheng
BIBINF in: Third International Congress on Building Energy Management, III Ventilation, air movement and air quality: field measurement and energy auditing, held in Lausanne, Switzerland, September 28- October 2, 1987, p52-57, 3 figs, 3 tabs, 2 refs. #DATE 00:09:1987 in English

#NO 2880 Approaches to estimating airflows in large multi-family buildings.
AUTHOR Bohac D L
BIBINF Ashrae Trans, Vol 93, Part 1 1987, p1335-1358, 8 figs, 6 tabs, 19 refs. #DATE 00:00:1987 in English

#NO 2959 The modelling of stairwell flows.
AUTHOR Reynolds A J, Mokhtarzadeh-Dehghan M R, Zohrabian A S
BIBINF Building and Environment, Vol 23, No 1, pp 63-66, 1988, 1 tab, 1 ref. #DATE 00:01:1988 in English

#NO 3131 Zone to zone tracer gas measurements; laboratory calibration and values of air flows up and down stairs in houses.
AUTHOR Riffat S B, Walker J, Littler J
BIBINF in: "Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. #DATE 00:09:1988 in English

#NO 3135 A numerical study of buoyancy-driven flows of mass and energy in a stairwell.
AUTHOR Zohrabian A S, Mokhtarzadieh-Dehghan M R
BIBINF in: " Effective Ventilation", 9th AIVC Conference, Gent, Belgium, 12-15 September, 1988. #DATE 00:09:1988 in English

#NO 3376 Stairwell pressurization in a cold climate.
AUTHOR Clark J A, Harris J W
BIBINF Preprint: Ashrae Transactions, Vol 95, Part 1, 5pp, 3 figs, 3 refs. #DATE 00:00:1989 in English

#NO 3459 Full scale smoke control tests at the Plaza Hotel building.
AUTHOR Klote J
BIBINF ASHRAE Journal, April 1989, pp.28-32, 1 tab, 7 refs. #DATE 00:00:1989 in English

#NO 3583 Buoyancy-driven air flow in a closed half scale stairwell model: velocity and temperature measurements.
AUTHOR Zohrabian A S, Mokhtarzadeh-Dehghan M R, Reynolds A J
BIBINF in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp167-187, 7 figs, 6 tabs, 18 refs. #DATE 00:02:1990 in English

#NO 3609 Ventilation and indoor air quality in a modern office building.
AUTHOR Grot R A, Persily A, Hodgson A T, Daisey J M
BIBINF in: UK, 9th Conference AIVC, "Effective Ventilation" Gent , Belgium, 12-15 September 1988, Vol.2, pp303-326, 25 figs, 1 tab, 4 refs. #DATE 00:09:1988 in English

#NO 3826 Heat distribution by natural convection.
AUTHOR Balcomb J D, Yamaguchi K
BIBINF in Proceedings 8th National Passive Solar Conference, Sante Fe, NM, Boulder, CO, USA: ASES, 1983. #DATE 00:00:1983 in English

#NO 3835 Description and preliminary validation of a model for natural convection heat and air transport in passive solar buildings.
AUTHOR Jones G F, Balcomb J D
BIBINF USA, in Proceedings 10th National Passive Solar Conference, 1985. #DATE 00:00:1985 in English

#NO 3893 Improvement of air quality in schools by enhanced air transfer.
Battre luftkvalitet i skolar genom forcerad overluftsforing.
AUTHOR Vikstrom P
BIBINF Sweden, Stockholm, Swedish Council for Building Research, R77:1989, 28pp.#DATE 00:00:1989 in Swedish

#NO 3904 Smoke control technology. Overview.
AUTHOR Klote J H
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp1-8, 2 figs, 2 tabs, refs.#DATE 00:00:1989 in English

#NO 3906 Pressure drop characteristics of typical stairshafts in high-rise buildings.
AUTHOR Achakji G Y, Tamura G T

BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp45-50, 9 figs, 2 tabs, refs. #DATE 00:00:1989 in English

#NO 4331 Condensation, heating and ventilation in small houses.
AUTHOR Raw G J, Fox T A
BIBINF Netherlands, International CIB W67 Symposium, "Energy, moisture and climate in buildings", 3-6 September 1990, Rotterdam, pl27, 1 tab. #DATE 00:09:1990 in English

#NO 4560 Stair pressurization systems for smoke control: design considerations.
AUTHOR Tamura G T
BIBINF USA, ASHRAE Transactions, Vol 95, Pt 2, 1989, 9pp. #DATE 00:00:1989 in English

#NO 4680 Nighttime ventilation by stack effect.
AUTHOR van der Maas J, Roulet C-A
BIBINF USA, Ashrae Transactions, Vol 97, Part 1, 1991, Preprint, 9pp, 7 figs, refs. #DATE 00:00:1991 in English

#NO 4845 Two-directional air movements in stairwells.
AUTHOR Edwards R, Irwin C
BIBINF UK, AIVC 11th Conference, "Ventilation System Performance", held 18-21 September 1990, Belgirate, Italy, Proceedings published March 1990, Volume 1, pp 379-388, 4 figs, 1 tab, 3 refs. #DATE 00:03:1991 in English

#NO 5123 An evaluation of a network smoke control model.
AUTHOR Said M N A, MacDonald R A
BIBINF Preprint, USA, ASHRAE Transactions, Vol 97, Pt 1, 1991, 13 figs, refs. #DATE 00:00:1991 in English

#NO 5125 Overall and component airtightness values of a five-storey apartment building.
AUTHOR Shaw C Y, Magee R J, Rousseau J
BIBINF Preprint, USA, ASHRAE Transactions, Vol 97, Pt 2, 1991, 11 figs, refs. #DATE 00:00:1991 in English

#NO 5145 Stair pressurization systems for smoke control.
AUTHOR Tamura G T
BIBINF USA, Ashrae Journal, July 1991, pp 14-18, 3 figs, 15 refs. #DATE 00:07:1991 in English

#NO 5265 Airflow patterns in a five-storey apartment building.
AUTHOR Shaw C, Reardon J, Said M, Magee R
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 1, pp 359-374. #DATE 00:09:1991 in English

#NO 5582 Field tests on staircase pressurization system in Hong Kong.
AUTHOR Chow W K, Lam Wai L, Cheung K P, Lam K C
BIBINF USA, Ashrae, Far East Conference on Environmental Quality, held Hong Kong, 5-8 November 1991, pp 27-38, 13 figs, 3 tabs, refs. #DATE 05:11:1991 in English

#NO 5589 An experimental study of maximum allowable pressure differences for staircases.
AUTHOR Xu Ming
BIBINF USA, Ashrae, Far East Conference on Environmental Quality, held Hong Kong, 5-8 November 1991, pp 163-165, 6 figs, 4 tabs, refs. #DATE 05:11:1991 in English

#NO 5633 Assessment of stair pressurization systems for smoke control.
AUTHOR Tamura G T
BIBINF USA, Ashrae, Transactions, Vol 98, Part 1, 1992, 7pp, 5 figs, refs. #DATE 00:00:1992 in English

#NO 6029 Two- and three-dimensional finite-volume predictions of flow in a stairwell and comparison with experiment.
AUTHOR Ergin-Ozkan S, Mokhtarzadeh-Dehghan M R, Reynolds A J
BIBINF Japan, Society of Heating, Air Conditioning and Sanitary Engineers of Japan, 1992, proceedings of the International Symposium on Room Air Convection and Ventilation Effectiveness - ISRACVE, held at the University of Tokyo, 22-24 July, 1992, pp 201-206. #DATE 22:07:1992 in English

Other References

ASHRAE (1987), Fire and Smoke control. HVAC Handbook. pp58.1 - 58.16.

McNemar J, (1976), Emergancy stairwell ventilation. ASHRAE Journal. July 1975. pp44 - 46.

Reynolds A J (1986), The scaling of flows of energy and mass through stairwells. Building and Environment. Vol 21, pp149-??

Shaw and Tamura (1976), Design of a stairshaft pressurization system for tall buildings. ASHRAE Journal Feb. 1976. pp29 - 33.SEE REF #299.

5 (c). Lift Shaft References.

#NO 140 Pressure differences for nine-storey building as a result of chimney effect and ventilation system operation.
AUTHOR Tamura G.T. Wilson A.G.
BIBINF ASHRAE trans vol 72 p180-189 #DATE 24:01:1966 in English #AIC 1257

#NO 299 Air leakage data for the design of elevator and stair shaft pressurization system.
AUTHOR Tamura G.T. Shaw C.Y.
BIBINF ASHRAE trans vol 82 part 2 p179-190 8 figs, 3 tabs, 8 refs. D.B.R. Paper No. 717 #DATE 01:06:1976 in English

#NO 1489 Disturbances in ventilation systems. Part 1 and Part 2
AUTHOR Rydberg J.
BIBINF Heat.Vent.Engr. May 1960, 483-485,489, June 1960, 541-547, 9 figs, 2 refs. #DATE 00:05:1960 in English #AIC 928A and

#NO 2058 Natural Venting to Control Smoke Movement in Buildings Via Vertical Shafts.
AUTHOR Tamura, G. T.; Wilson, A. G.;
BIBINF RESEARCH.LOC = Ottawa, Canada; TYPE = REPORT; #DATE 01:07:1970; VOLUME.TITLE = ASHRAE Trans.; VOLUME.NO = 76; PAGES = 279-289; REPORT.NO = 2162; PUBLISHER.NAME = ASHRAE; in English

#NO 3609 Ventilation and indoor air quality in a modern office building.
AUTHOR Grot R A, Persily A, Hodgson A T, Daisey J M
BIBINF in: UK, 9th Conference AIVC, "Effective Ventilation" Gent , Belgium, 12-15 September 1988, Vol.2, pp303-326, 25 figs, 1 tab, 4 refs. #DATE 00:09:1988 in English

#NO 3904 Smoke control technology. Overview.
AUTHOR Klote J H
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp1-8, 2 figs, 2 tabs, refs. #DATE 00:00:1989 in English

#NO 3905 Information-based smoke control systems.
AUTHOR Shavit G
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp37-43, 5 figs,refs. #DATE 00:00:1989 in English

#NO 3908 Experimental fire tower studies of elevator pressurization systems for smoke control.
AUTHOR Tamura G T, Klote J H
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp61-72, 6 figs, 8 tabs, refs. #DATE 00:00:1989 in English

#NO 3909 Experiments of piston effect on elevator smoke control.
AUTHOR Klote J H, Tamura G T
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp73-78, 4 figs, 1 tab, refs. #DATE 00:00:1989 in English

#NO 3910 Presently, elevators are not safe in fire emergencies.
AUTHOR Sumka E H
BIBINF USA, in: ASHRAE Technical Data Bulletin, Vol 5, No 2, 1989, pp79-82, 1 fig, 2 tabs, refs. #DATE 00:00:1989 in English
Copies of the documents listed in the previous pages are available from the Air Infiltration and Ventilation Centre (Details on back page.)

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Finvac
Cold Climate HVAC '94
International Conference on HAVC in Cold Climates
15-18 March 1994
Rovaniemi, Finland
Contact: Conference Secretariat, FINVAC/ Cold Climate HVAC '94, Mr Ilpo Nousainen, Sitratori 5, SF-00420 Helsinki, Finland
Tel: +358 0 563 3600
Fax: +358 0 566 5093

BEP '94
Building Environmental Performance: Facing the Future: 2nd BEPAC Conference
5-8 April 1994
York, UK
Contact: Mrs Rhona Vickers, AIVC, Sovereign Court, Sir William Lyons Road, Coventry CV4 7EZ

ECEMEI
European Congress on Economics and Management of Energy in Industry
5-9 April 1994
Estoril, Lisbon, Portugal
Contact: ECEMEI, c/o Prof Albino Reis, Rua Gago Coutinho, 185-187, 4435 Rio Tinto, Portugal
Tel: 351 2 973 07 47
Fax: 351 2 9730746

Globalcon '94
The Conference and Expo on Energy and the Environment
6-7 April 1994
Anaheim Convention Center, Anaheim, California, USA
Features five concurrent programs:
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Contact: Globalcon '94, 4025 Pleasantdale Road, Suite 420, Atlanta, GA 30340, 4264, USA
Tel: 404 447 5083 x 210
Fax: 404 446 3969

First International Conference
Buildings and the Environment
CIB Task Group 8: Environmental Assessment of Buildings
16-20 May 1994
Building Research Establishment, Garston, Watford, UK
Contact: Andrew Cripps, Building Research Establishment, Garston, Watford, WD2 7JR, UK

European Simulation Multiconference
1-3 June 1994
Barcelona, Spain
Contact: Barcelona ESM '94 General Information, The Society for Computer Simulation International, European Simulation Office, c/o Philippe Geril, University of Ghent, Coupure Links 653, B-9000 Ghent, Belgium
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International Symposium on Underground Openings for Public Use
14-17 June 1994
Gjøvik, Norway
Contact: NIF, PO Box 2312 Solli, N-0201 Oslo, Norway
Topics: Rock Engineering; Heating Ventilation and Air Conditioning in Rock Caverns; Fire Safety and Escape Strategies; Psychological Impact; Case Histories; Special Session on the Gjovik Olympic Rock Stadium

Roomvent '94 Fourth International Conference on Air Distribution in Rooms
15-17 June 1994
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Contact: Conference Secretariat, Roomvent '94, Dept of Heating, Ventilating and Dust Removal Technology, Silesian Technical University, Pstrowskiego 5, 44-101 Gliwice, Poland
Tel: +48 32 37 1280
Fax: +48 32 37 25 59

PLEA '94
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Architecture of the Extremes
Eleventh PLEA International Conference
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Dead Sea, Israel
Contact: 11th International PLEA Conference Secretariat, Peltours, Te'um Congress Organizers, PO Box 8388, Jerusalem, 91082, Israel
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Fax: 972 2 637572

CISS First Joint Conference of International Simulation Societies
August 22-25 1994
ETH Zurich, Switzerland
Contact: Juergen Halin, ETH Zurich, Institute of Energy Technology, Clausiusstrasse 33, CH-8092 Zurich, Switzerland

Healthy Buildings '94
CIB-ISIAQ-HAS Conference
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Budapest, Hungary
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Applications Guide 1 (1986) Liddament, M.W. 'Air Infiltration Calculation Techniques - An Applications Guide'

Applications Guide 2 (1988) Charlesworth, P.S. 'Air Exchange Rate and Airtightness Measurement Techniques - An Application Guide'

Handbook (1983) Elmroth, A. Levin, P. 'Air infiltration control in housing. A guide to international practice.'

TECHNICAL NOTES

TN 5.1 (1983), **5.2** (1984), **5.3**(1985), **5.4**(1988) Allen, C. .OSS'; Air Infiltration Glossaries (German, French, Italian ıtch) Supplements.

TN 10 (1983) Liddament, M,, Thompson, C. 'Techniques and instrumentation for the measurement of air infiltration in buildings - a brief review and annotated bibliography'

TN 11 (1983) Liddament, M., Allen, C. 'The validation and comparison of mathematical models of air infiltration'

TN 13 (1984) Allen,C. 'Wind pressure data requirements for air infiltration calculations'

TN 13.1 (1984) '1984 Wind Pressure Workshop Proceedings' .

TN 16 (1985) Allen,C. 'Leakage Distribution in Buildings'

TN 17 (1985) Parfitt, Y. 'Ventilation Strategy - A Selected Bibliography'

TN 20 (1987) 'Airborne moisture transfer: New Zealand workshop proceedings and bibliographic review'

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TN 26 (1989) Haberda,F and Trepte,L. IEA Annex IX 'Minimum ventilation rates and measures for controlling indoor air quality.

TN 27 (1990) Bassett, M. 'Infiltration and leakage paths in single family houses. A multizone infiltration case study.'

TN 28 (1990) Sutcliffe, H. 'A guide to air change efficiency.'

TN 28.2 (1991) Brouns C, Waters JR, 'A guide to contaminant removal effectiveness'.

TN 29 (1990) Feustel, H E, et al 'Fundamentals of the multizone air flow model - COMIS.'

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TN34 (1991) Roulet C-A, Vandaele L 'Air flow patterns within buildings: measurement techniques.'

TN35 (1992) Knoll B 'Advanced ventilation systems - state of the art and trends.'

TN36 (1992) Limb M J 'Airgloss Air Infiltration Glossary'.'

TN 37 (1992) Liddament M W, 'A Strategy for Future Ventilation Research and Applications',

TN 38 (1992) Limb M J 'AIRGUIDE: Guide to the AIVC's Bibliographic Database'.

TN 39 (1993) Liddament M W "A Review of Ventilation Effeciency".

TN 40 (1993) Kendrick J F, "An Overview of Combined Modelling of Heat Transport and Air Movement".

TN 41 (1993) Wilson D and Walker I, "Infiltration Data from the Alberta Home Heating Research Facility".

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13th 'Ventilation for Energy Efficiency and Optimum Indoor Air Quality', France, 1992;

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