INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme

7th AIVC Conference

Occupant Interaction with Ventilation Systems

Supplement to Proceedings

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Annex V Air Infiltration and Ventilation Centre

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PREFACE

International Energy Agency

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Programme was formulated among a number of industrialised countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Cooperation and Development (OECD) to administer that agreement. Twenty-one countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Programme, the Participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat staff, coordinates the energy research, development, and demonstration programme.

Energy Conservation in Buildings and Community Systems

As one element of the Energy Programme, the IEA encourages research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is encouraging various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring, comparison of calculation methods, as well as air quality and inhabitant behaviour studies.

The Executive Committee

Overall control of the R&D programme "Energy Conservation in Buildings and Community Systems" is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures all projects fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication.

Annex V Air Infiltration and Ventilation Centre

The IEA Executive Committee (Building and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous agreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial groundwork the experts group recommended to their executive the formation of an Air Infiltration and Ventilation Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardisation of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and, based on a knowledge of work already done, to give direction and firm basis for future research in the Participating Countries.

The Participants in this task are Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States of America.

INTRODUCTION

This document is a supplement to the AIVC's 7th Conference Proceedings, AIC-PROC-7-86. It contains six additional papers, five of which were presented at the Conference, together with a discussion record based on written questions and answers prepared by conference participants and authors.

OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER S.1

VENTILATION AND ENERGY EFFICIENCY - Keynote Address

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Introduction

1. The Energy Efficiency Office provides the United Kingdom's subscription to the Air Infiltration and Ventilation Centre. This is appropriate since improved energy efficiency must be a principal goal of air infiltration studies. Through better understanding of infiltration rates and occupants' needs, we are able to design and construct buildings which provide adequate but not excessive ventilation for their occupants, and can thus minimise the energy demand arising from ventilation requirements.

2. In this address, therefore, I wish:

a) to set an energy efficiency context for research into air infiltration;

b) to summarise current research themes;

and c) to suggest aims for research in air infiltration and occupant behaviour.

I hope that this will provide Conference participants with a suitable framework in which to place subsequent papers.

Energy Use and the Energy Efficiency Office

3. In 1984, the United Kingdom used 8161 PJ of primary energy while consumption by final users amounted to 5682 PJ (Reference 1). Table 1 shows how final and primary energy uses were distributed among different sectors of the UK economy; a similar pattern may be observed in most European countries. In the USA and Canada, though, the transport sector accounts for a rather higher proportion of final energy use.

4. It is clear that energy uses in buildings account for a large proportion of the UK's energy consumption. All consumption in the 'domestic' and 'commercial/institutional' sectors and some in the 'industry' sector can be attributed to buildings. In primary energy terms, buildings account for approximately one half of the national total; in final use terms, the proportion is somewhat less because of the smaller conversion losses in industry and the transport sector, a reflection of the lower use of electricity in these sectors.

5. Space heating is the dominant energy use in most classes of building. Taking major sectors, Table 2 shows the distribution of energy use in the domestic sector and Table 3 the distribution in commercial and institutional buildings, both in primary energy terms (Reference 2). Energy savings in space heating may be made though improvements to fabric insulation, glazing, heating and control systems and through reduction of infiltration. The relative importance of each will vary widely according to the type, size and construction of the building.

6. Over the UK economy, savings of at least 20%, worth £7 billion per annum, are possible through measures that will pay for themselves in timescales acceptable to the energy consumers concerned. In industry, this in general means pay-back periods of less than two years. For

buildings, longer pay-back periods - perhaps up to 7-8 years - are accepted. The Energy Efficiency Office was created within the Department of Energy in 1983 to devise and administer programmes that would alert all energy users to the potential for cutting their energy costs and would help to achieve greater efficiency in energy use. Through these programmes, the EEO aims to strengthen the underlying trend towards improved energy efficiency in the UK economy and to secure this 20% improvement by the mid-1990's.

7. The annual budget of the Energy Efficiency Office is about £25million. Its principal programmes

(i) advertising and advice aimed at all energy use sectors, but particularly domestic consumers;

(ii) breakfast-time seminars for executives in both public and private sectors, addressed by Ministers (16000 executives attended the first series);

(iii) grants towards the cost of energy surveys in industry and non-domestic buildings;

(iv) grants towards the installation of novel technology for improving energy efficiency, independent monitoring of performance in use and vigorous promotion of the results if successful;

(v) development of improved management techniques for energy use in industry and commerce;

(vi) improvement of energy efficiency in Government and other public sector buildings;

(vii) insulation and draught-stripping of homes of low-income householders.

8. Underpinning these activities is an R & D programme which covers a wide range of studies from the co-funding with firms of new technological developments to evaluating the relative effectiveness of different approaches to the promotion of energy efficiency. The Office's support for the AIVC comes from this programme.

Ventilation and Energy Use

9. In recent years, stimulated initially by the sharp rise in energy prices in the early 1970's, insulation standards in new buildings have risen substantially. This change, however, increases the relative contribution of ventilation losses to total space heating requirements. Table 4 shows how fabric and ventilation losses changed in a typical UK semi-detached house between 1970, when no thermal insulation standards were included in Building Regulations, and 1980, when Regulations set maximum 'U' values of 1.0 W/m^2K for walls and 0.6 W/m^2K for roofs. The Table also gives a possible future figure, for a time when maximum U-values might be around 0.3 W/m^2K. It is clear that control of infiltration becomes increasingly important.

10. These average figures disguise another effect which makes ventilation losses even more important in relation to comfort - the variation with wind direction. As ventilation losses become a larger component of total demand, rapid variations in room ventilation rate as the wind changes direction, with consequent variations in the heating load, mean that the heating system must be properly sized and controlled to be able to respond. Figure 1 illustrates this effect.

11. Calculations such as those on which Table 4 is based always have to assume an average 'whole house' ventilation rate. One air change per hour (1ach) is often chosen, because it represents adequate but not excessive ventilation. The actual ventilation rates experienced in real houses, however, vary considerably. Tracer gas techniques provide direct measurements of ventilation rates. However, they are time consuming and expensive, and in the UK relatively few measurements - mainly of whole house infiltration rates - have been made. Figure 2 gives the distribution of whole house infiltration rates for 430 measurements in a sample of 26 houses (Reference 3); the mean is 0.7ach and the tail of the distribution extends just beyond 2ach.

12. Fan pressurisation is much simpler, and although this gives information on the air leakage characteristics of a building rather than the air infiltration rate, calibration through tracer gas studies does allow the infiltration rate to be estimated with reasonable accuracy. In particular, the leakage rate at 50Pa applied pressure can be a good indicator of whether natural infiltration is normally inadequate, excessive or satisfactory. Figure 3 shows the distribution of leakage rates at 50Pa in a sample of 100 UK dwellings (Reference 4); generally acceptable values lie in the range of 10-20ach (with doors and windows closed, and flues sealed).

13. These recent measurements by the Building Research Establishment and others indicate that the spread of infiltration rates in the UK housing stock is considerably narrower than was previously considered likely, with far fewer dwellings now expected to have highly excessive ventilation rates. Nationally, perhaps some 30-40% of the present stock could benefit from reduced infiltration rates, The current BRE view is that the majority would be limited to a reduction of no more than 0.5ach on safety and other grounds. The national annual primary energy savings would be about 40 PJ.

14. Thus the energy savings to be obtained through reduced infiltration in UK housing are equivalent to some 2% of domestic energy consumption or 4% of domestic space heating consumption, and are worth over £100 million annually. Savings in non-domestic buildings are probably in the £50-100 million range, but there is little information on which to base an estimate.

Constraints on ventilation control

15. Control of infiltration can thus make a significant contribution to improved energy efficiency. However, in providing advice on how to reduce infiltration rates, or attempting to specify rates in Regulations, official bodies such as the Energy Efficiency Office face a number of problems.

16. First, there is, in the UK at any rate, considerable uncertainty about the minimum ventilation rate required for safety and comfort. If ventilation is inadequate, the water vapour produced in the course of domestic activities will remain in the dwelling and will eventually condense on cold surfaces, with resulting problems of mould and damage to the fabric. The other pollutants produced by human activities and by furnishings - tobacco smoke, formaldehyde, combustion products etc - also have to be removed and the need to control radon originating in the ground has recently been identified as an important factor in some areas of the UK. In general, however, the dominant pollutant is water vapour. The UK climate is characterised by high relative humidity and many houses show signs of condensation problems - Table 5 shows the results of one survey of English houses. In order to avoid such problems, BRE recommend a whole house ventilation rate of around 0.7ach, with specific recommendations for rooms with moisture generating activities, eg bathrooms, and other special circumstances.

17. Secondly, even if one could specify precisely the required average ventilation rate, there are no simple methods for deciding upon the measures that should be adopted in order to achieve this rate. Mechanical ventilation, combined with heat recovery and a very tight construction, is one option. This is rarely used at present in the UK because of its cost, and most dwellings will for the foreseeable future depend upon natural ventilation and infiltration. The infiltration rate in new buildings will depend upon factors such as the form of construction, the quality of workmanship, internal layout and the exposure of the site. Moreover, it will tend to increase in the first year or two owing to settlement, drying out etc. In existing buildings, only general guidance on the measures to be adopted can be given since the rates for air infiltration will not be known in detail. Moreover, until recently, there was very little objective information available on the performance of even common means of reducing infiltration e.g. the various methods of draught-proofing doors and windows. As a result of recent BRE research, some funded by the EEO, it is now possible to specify the most appropriate material for different situations. This is, however, by no means the complete answer to the problem of specifying measures appropriate to a particular building.

18. Thirdly, there is a lack of convenient testing procedure which can identify infiltration routes and enable builders to check whether targets or mandatory requirements have been met. Ideally, tracer gas techniques would provide the most accurate measurement of air infiltration rates. However, the time and expense involved makes this approach quite unsuitable. Pressure testing has become a recognised proxy technique. Whole-house pressurisation is specified in building standards in Norway and Sweden, and in draft standards in North America, where builders use it for quality control and developers find it a useful selling point. Furthermore, most industrial countries have pressurisation standards for building components such as windows. In the UK, BRE has produced a protocol on pressure testing drawing upon overseas experience as well as that of BRE and the very limited number of other UK practitioners. At present, since the Building Regulations contain no specific infiltration requirements, this protocol is used mainly as a guide for UK ventilation research groups. The routine use of test procedures by housebuilders is some way off.

19. Finally, even if rates could be specified, achieved in practice and checked, there would remain the influence of the building's occupants - which is the theme for this conference. If, for whatever reason, they decide that the ventilation provided is inappropriate, they will open windows or stop up ventilators. Custom and practice, just as much as reactions to the local environment, will I suspect have a large influence here. You will, though, be considering this over the next three days and I shall not say more now.

20. The conclusion I draw from this is that at the moment it is not realistic to include requirements on ventilation rates in UK Building Regulations. They could not be specified with sufficient confidence, nor could conformance be monitored. However, non-statutory documents should certainly include guidance on the control of infiltration. Thus the advisory material available from bodies such as the EEO covers the principal ways in which householders can reduce draughts. And professional codes, such as those of the British Standards Institution, can promote good practice in control of infiltration.

Current Research

21. Funding for UK research relevant to the control of infiltration comes in general from public sector sources, primarily the Department of the Environment, the Energy Efficiency Office, the Science and Engineering Research Council and the public sector fuel industries. Research is in progress at the Building Research Establishment, the research establishments of the Electricity Council and British Gas, the Building Services Research and Information Association (BSRIA) and a number of university and private sector laboratories.

22. Research is aimed at the four main problem areas outlined above. First, how can one establish appropriate ventilation rates? BRE is studying the incidence of condensation problems and measures for countering them, including extra ventilation, fungicides and dehumidifiers. Another programme is studying mould growth in timber and the effects of wood preservative while the main ventilation research section at BRE is studying indoor air quality requirements and standards.

23. Secondly, how can one specify appropriate control measures and predict their performance? BRE, with some university and private sector laboratories, is conducting a major investigation into air leakage rates in dwellings, together with model studies. This should provide the first large scale experimental measure of infiltration rates, and hence of infiltration heat losses, in UK dwellings. I have already referred to some results from this investigation. BRE with BSRIA have also been developing techniques to investigate ventilation mechanisms in larger buildings. The Princes Risborough (timber) Laboratory of BRE has made detailed assessments of door and window draughtstripping products, the latter being funded by the EEO, and used these tests to develop suitable test procedures for incorporation in future British Standards. Figure 4 illustrates how some of the findings from these studies have been translated into simple advisory material aimed at the general public.

24. Thirdly, how can infiltration rates be conveniently measured and buildings checked for compliance with a mandatory level of

performance? BRE and the Polytechnic of Central London are investigating simplified tracer gas techniques, giving time-averaged rather than varying infiltration rates. The combination of a calibration rig for pressure testing and the publication of a protocol should lead to improved apparatus and techniques for pressure testing. An alternative design of measurement rig has been developed in a private sector laboratory with assistance from the EEO. Most university research into ventilation, funded by the Science and Engineering Research Council, has been in the general area of tracer gas techniques, and also in computer modelling studies. The British Gas Corporation has also had a programme of research in this general area.

25. Finally, occupants' reaction to the internal environment, and their response to different means of providing ventilation, has been studied in the past by the Electricity Council Research Centre and more recently through the BRE research programme (eg the study of window opening in office blocks published in 1984 - Reference 6) and through demonstrations and field trials in housing. Under the EEO's demonstration programme, trickle ventilators were installed at one housing estate with beneficial results while the Electricity Council have conducted field studies of mechanical ventilation in tightly-constructed houses with very positive reactions from occupants and more extensive trials are now in progress. These ventilation systems, equipped with heat recovery, provide an estimated 1/3ach at their normal setting and this appears to satisfy the occupants' needs. The cost of such systems - £1000 or more - is, though, high in relation to reduction in annual energy costs achieved.

Conclusions

26. In this address, I have attempted to show the contribution that proper control of infiltration can make to the improvement of energy efficiency in the UK, to consider the barriers to specifying infiltration rates in Regulations or in providing precise guidance on control measures, and to pick out the main features of research in progress in the UK relevant to these problems. I must now sum up and let you proceed to the papers which you have come to hear, and which will take this subject forward.

27. My aim has been to show that this is not a subject to be pursued primarily for its own sake, fascinating and complex though some of the aspects are. It is a deeply practical subject, with great relevance to the new problems that householders face in combating condensation and keeping warm at minimum cost and the legitimate concern of all building owners that their buildings should be weather-tight, economical to run and comfortable to live and work in. The aim of research should therefore be to advance knowledge in such a way that it can be of practical assistance to building owners and occupiers - accepting, of course, that research results have often to be 'translated' for building professionals and others through incorporation in Codes, advisory leaflets etc before they are accessible to their ultimate users.

28. Those engaged in air infiltration research should therefore be consciously working towards the development of low-risk construction practices which reduce infiltration in new buildings while maintaining

acceptable indoor air quality and avoiding condensation risks, or contributing towards the development and specification of acceptable means of modifying existing buildings, and the ability of regulators to specify and monitor ventilation requirements.

29. In considering the output from current research, and plans for future studies, therefore, certain questions come to mind:

> Which problem area is this work addressing?
>
> Who will use the results - and how can they be best presented for this purpose?
>
> How much benefit will it bring through application?

30. The AIVC has, I believe, an important role here, not just in facilitating communication within the research community but in stimulating discussion of the means of presentation to the construction industry. Its recent change of title marks, I think, a recognition of this role. The Energy Efficiency Office stands ready to assist in getting research applied as, no doubt, do its counterparts in other countries. We want to make use of the best information available, to help us achieve the energy efficiency targets set for us. Your discussions here, and the other work of the AIVC, can help set us on the path to the £100 million or more savings to be achieved in this country through better control of infiltration, a sum which can be multiplied many times across IEA Members. As you listen to the presentations of the next three days, I hope you will always have that goal in mind.

31. Thank you for your invitation, and for your attention. May I offer my very best wishes for the success of this conference.

Acknowledgement

I am grateful to Dr H Danskin and Dr P R Warren of the Building Research Establishment for their assistance in the preparation of this address.

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TABLE 1

UK Energy Consumption 1984 by Sector

	Final Use	Primary energy
	%	%
Domestic	27.9	30.0
Commercial/institutional	13.0	15.8
Transport	27.8	22.0
Industry	31.3	32.2
	100.0	100.0
Total consumption	5682 PJ	8161 PJ

Sources: References 1 and 2

TABLE 2

Distribution of energy use in the domestic sector

	(primary energy terms)
	%
Space heating	49
Water heating	21
Cooking	9
Lighting	4
Appliances	17

Source: Reference 2

TABLE 3

Distribution of energy use in commercial and institutional buildings

	(primary energy terms)
	%
Space heating	47
Water heating	10
Cooking/catering	9
Lighting	23
Other uses	11

Source: Reference 2

TABLE 4

Annual space heating consumption for typical house

	1970		1980		1990	
	GJ	%	GJ	%	GJ	%
Fabric	46.9	75	35.5	71	17.4	60
Ventilation	15.6	25	14.5	29	11.6	40
TOTAL	62.5	100	50	100	29	100

Notes:

1. '1970': U=1.5 W/m^2K for walls, 0.8 for roof, 0.6 for floor
2. '1980': U=1.0 W/m^2K for walls, U=0.6 for roof and floor
3. '1990': U=0.3 W/m^2K for walls, roof, and floor (hypothetical)
4. Ventilation rate assumed to be 1.2 ach in all cases; the annual energy consumption consequent on ventilation losses falls as the heating season is reduced through increased insulation.

TABLE 5

Incidence of problems caused by damp/condensation in England

	%
No condensation/damp	51
Steamed windows	37
Deterioration of paint on sills	13
Mould or damage to decorations	15
Damage to floors, carpets, furniture	3

Source: Reference 5

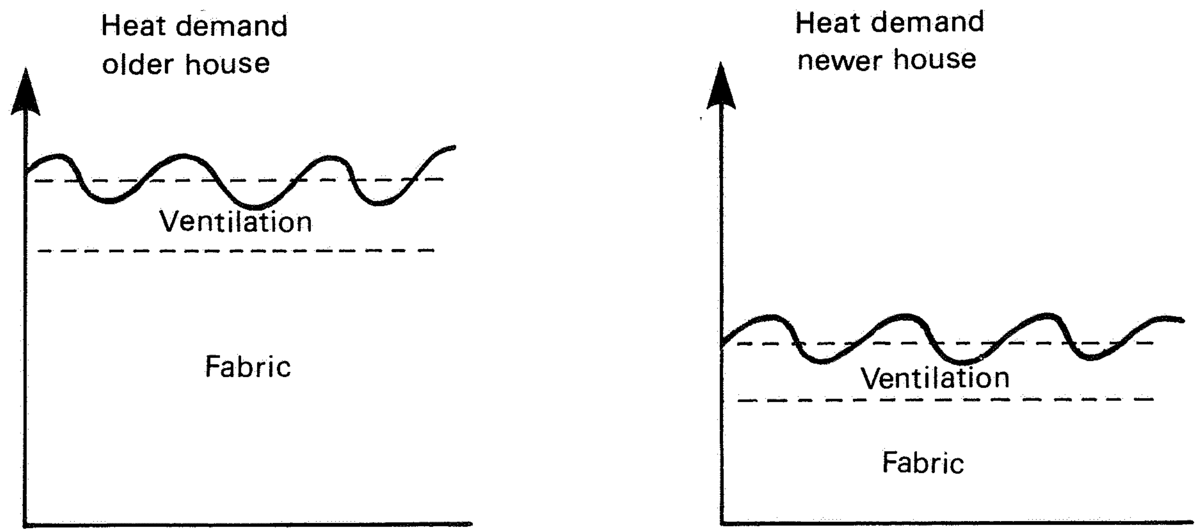


Figure 1 Variation in heat demand with wind strength and direction

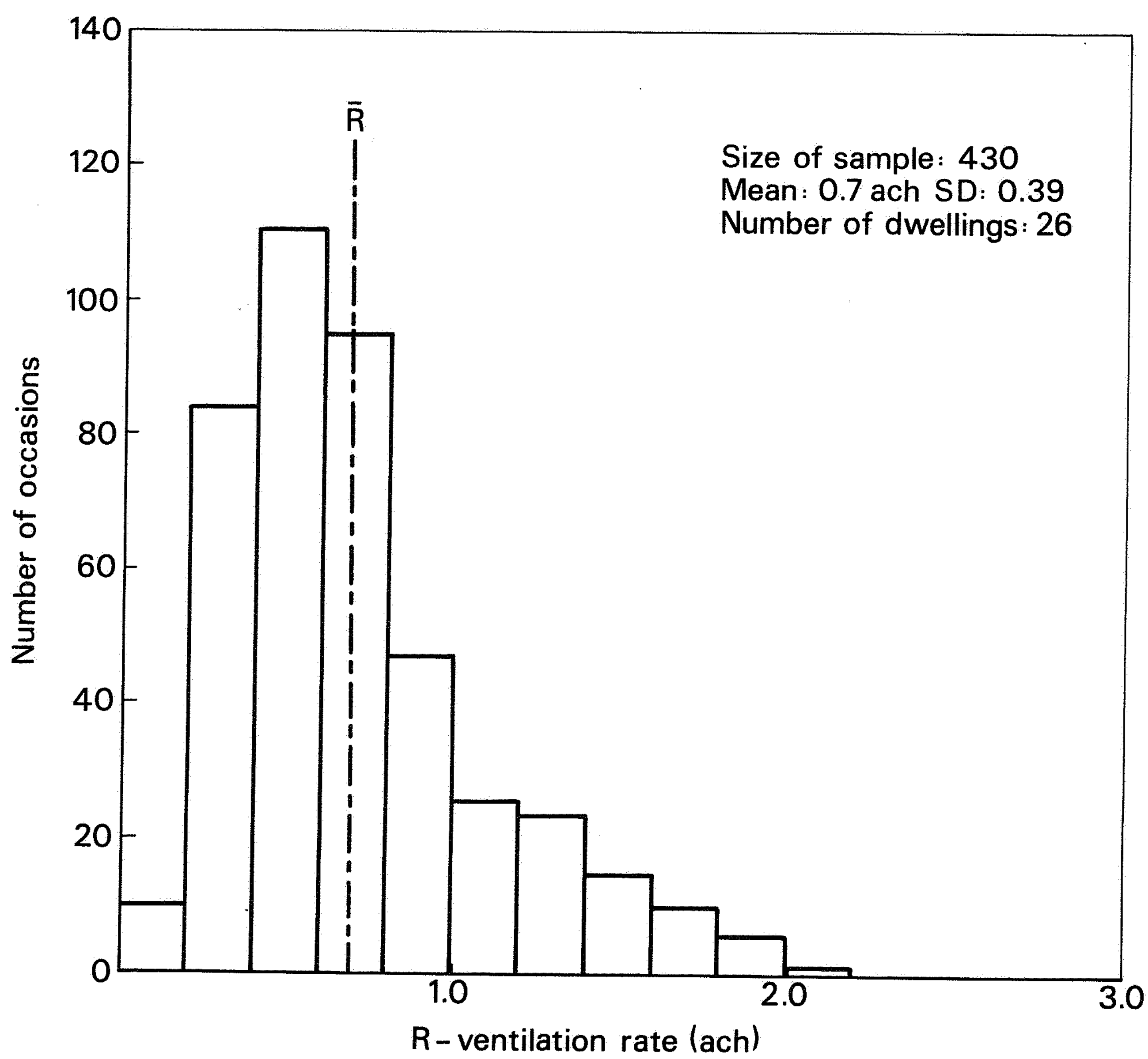


Figure 2 Distribution of whole house ventilation rates

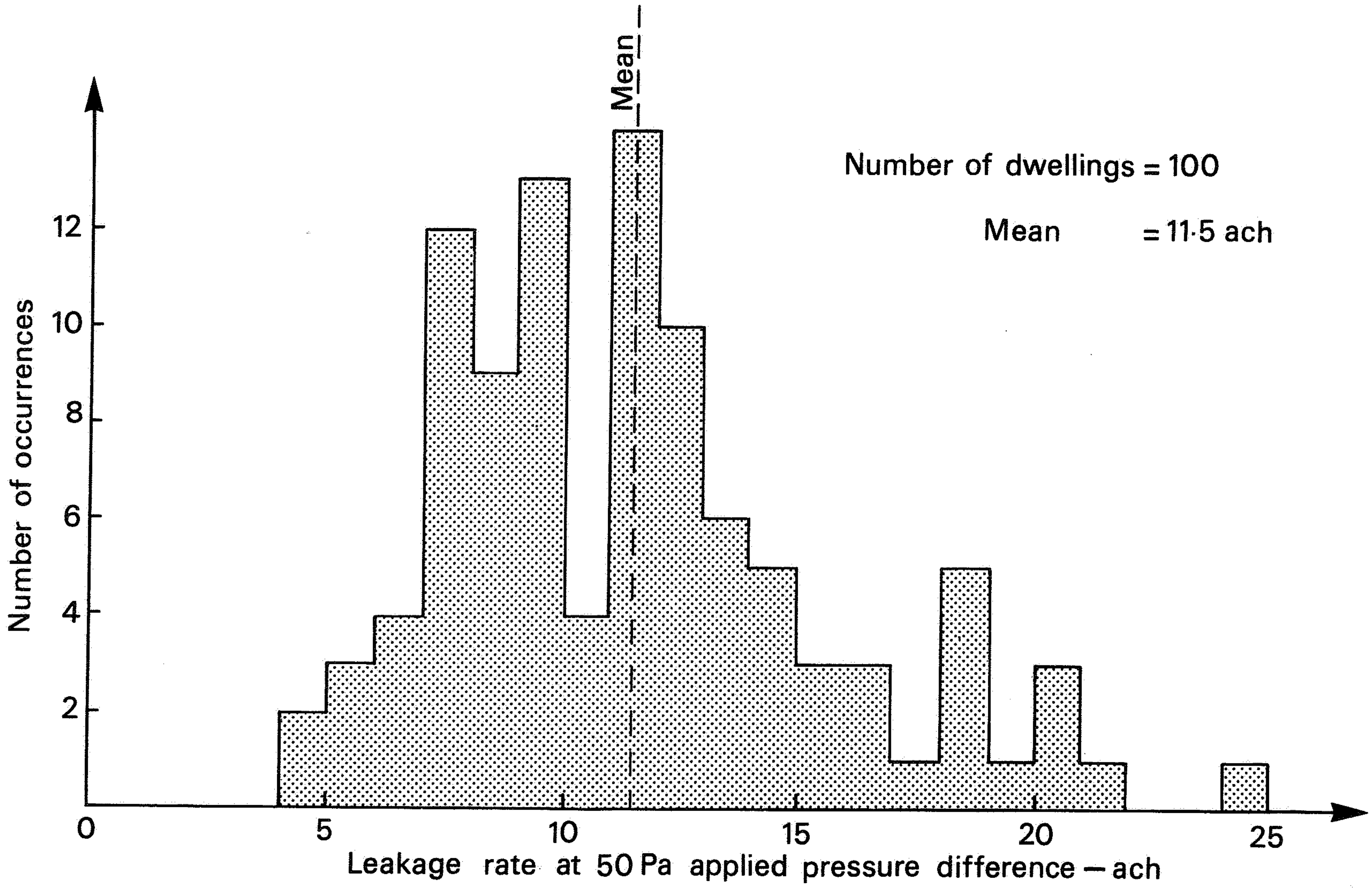
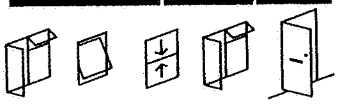


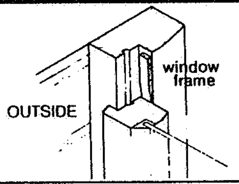
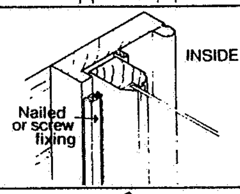
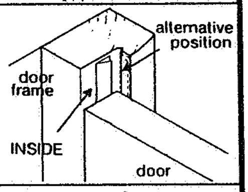
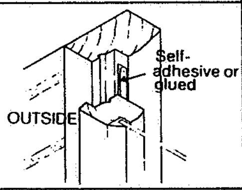
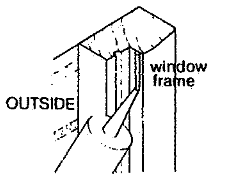
Figure 3 Distribution of whole house leakage rates at 50 Pa

Which One is Best for My Windows and Doors?

Look down the column and note which type of draughtstrip has the most stars for the type of windows and doors in your home.

Look across, to find out the best material, how it is fixed, how much it costs and any other particular features. The third column shows how the draughtstrips are normally fitted. Look on the draughtstrip packaging for more detailed information.



	Window – Wood	Window – Wood	Window – Wood	Window – Steel	Door		
Foams	***	**	X	***	**	**Best material** PVC foam with protective film. **Advantages** The quality of self adhesive strip has improved greatly. It is quick and easy to apply. Not visible when window is closed. Low cost. **Disadvantages** If used in small gaps, (under 2mm), needs a lot of force to compress. **Cost** 10 - 16p a metre for PVC foam, 30 - 65p a metre for EPDM rubber.	
	(suitable only for gaps over 1.5mm wide)						
Brushes	***	Y	***	X	**	**Best material** Soft nylon or polypropylene pile with central fin in a PVC or aluminium holder. **Advantages** Can be fixed to cope with a wide range of gap sizes. **Disadvantages** Brush piles should be removed when repainting. Visible when window or door is closed, but small PVC sections are unobstrusive. Fixing can be time-consuming. **Cost** 80p - £1.20 a metre. Self adhesive piles 30p - 50p a metre.	
Thin sections	**	**	**	***	***	**Best material** Flexible plastic **Advantages** Relatively cheap and easy to fix. Can cope with a wide range of gap sizes. **Disadvantages** The thin film may be prone to accidental damage, but can easily be replaced. When used as a wiper seal, it makes a 'crackly' noise when opening and closing, and may hum in high winds. **Cost** about 30 - 60p a metre for plastic V-strip.	
Shaped sections	***	***	X	***	**	**Best material** PVC or neoprene **Advantages** Very durable. Some are self-adhesive. **Disadvantages** Gluing sections in place with silicone sealant needs careful preparation, clean surfaces and some skill. Need to choose correct size of tubing relative to gap size. **Cost** about £1 - £2.50 a metre.	
	(suitable only for gaps over 1.5mm wide)						
Sealants	***	**	X	***	X	**Best material** Silicone rubber **Advantages** Very durable. Copes well with narrow and uneven gaps. **Disadvantages** Cannot cope with seasonal changes in gap size. Needs clean, well prepared surfaces and some skill to apply. Sealant needs to be left to cure before removing release tape and final trimming. **Cost** 60 - 80p per metre depending on gap size.	

KEY **X** = unsuitable **Y** = may be suitable - depends on the design of the windows

*** ** * The more stars the better the performance

Figure 4 Illustration of draught-proofing advice

OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
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PAPER S.2

INFLUENCE OF NIGHT-TIME VENTILATION REDUCTION ON INDOOR AIR QUALITY IN DANISH BLOCKS OF FLATS

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Synopsis

The paper describes the main results from a research project performed by "The Mobile Laboratory of Indoor Climate Measurements" one of the five mobile laboratories of the Institute. The aim of the project was to investigate if undesirable consequences occurred in the indoor climate when using an energy saving method consisting of reducing the mechanical exhaust from the "wet rooms" to app. 40 per cent of the normal performance during 12 hours of day and night.

The paper describes the selection of dwellings for the investigation, measuring methods and instruments, and the increase in indoor air humudity by using the reduction in ventilating mentioned. The conclusion is that in those 3 buildings from the investigation increases in the relative humidities were stated in a third of the dissipations on the 360 humidity measurings which formed a part of the investigation. The highest air humidities were measured in bedrooms.

Therefore, there is no reason to believe that the energy saving method should cause any health risks in the 3 buildings from the investigation.

1. Background

For many years, ventilation in Danish blocks of flats has been mechanical exhaustion from the "wet rooms", kitchen, bath, and toilet. The outdoor air replacing the exhaust air comes through the open windows and inlet valves, and through leakages in the building envelope.

In the two latest building regulations, BR 77 and BR 82, it is a demand that the exhaustion can be adjusted to a minor effect than the normal. The rating appears from table 1. However, the ventilation must not be switched off completely in bath-rooms and in toilets, in which it must be secured that the volume flow exhausted cannot be less than 40 per cent of the rated volume flow.

As the exhaust from bath-rooms and toilets, and the exhaust from ktchens normally is carried out by the same ventilation plant it is in fact a question of keeping the mechanical exhaust from the whole building at a minimum of 40 per cent of the rated.

In the building regulations it is not specified how many hours of day and night the ventilation must be at maximum effect.

During the recent years, still more building societies have used this possibility of reducing the exhaust-ventilation to save energy for heating of outdoor air and save energy to the ventilation engines. It is typically in 12 of the 24 hours that the ventilation runs with reduced performance e.g. from 9.00 to 12.00 o'clock and from 22.00 to 7.00.

1. Aim of the research project

The purpose of the project was to investigate if the reduction in ventilation caused undesired changes in the indoor climate of the flats. The project investigates the changes that occurred in concentrations of water vapour and CO_2. This paper includes only the measurements of the air humidities.

2. Selection of test-flats

To form part of the project the flats had to fullfil 2 demands:

1) They had to be supplied with mechanical ventilation from the "wet rooms".
2) It had to be possible to reduce the performance of the mechanical exhaust automatically at pre-set times.

2 buidings in the City of Copenhagen, and 1 building app. 20 km south of Copenhagen were chosen. Data concerning the buildings is stated in table 2. All inhabitants of the buildings were informed about the project, and those who wanted to participate were requested to contact The Danish Building Research Institute. Thus, the inhabitants, who took part in the investigation, were not chosen at random but have wanted and taken initiative to participate in the investigation.

3. Method of investigation

The investigation in each of the 3 buildings took place during a fortnight starting a Tuesday. The measuring instruments were prepared Monday at The Danish Building Research Institute. During the first measure-week the ventilation in one half of the measured flats was at maximum effect 24 hours a day and in the other half of the measured flats at a reduced effect 12 of the 24 hours. In the second week of measuring the running conditions of the ventilation were reversed in the two types of buildings. In each of the 3 buildings the measuring programme included measurements in 20 flats. Air temperature and relative air humidity were measured continuously in all kitchens. Furthermore, the weekly average of the relative air humidity in kitchens, living-rooms, and bedrooms was measured. Besides that, continuous measuring of the CO_2-concentration, air temperature, and relative air humidity in bedrooms was carried out in 6 flats. In all 60 flats the exhausted volume flows were measured when the ventilation plants ran on full speed. In at least one flat belonging to each ventilation plant in the investigation the exhausted volume flows were measured when the ventilation plants were at reduced effect. By mounting of the measuring instruments in the flats the inhabitants were questioned e.g. about their habits concerning airing, clothes-washing and -drying in the flats as well as number of inhabitants in the flat. Except for the space the measuring instruments took up in the flats, and that some measuring instruments were noisy it was not in any way connected with changes in the inhabitants' weekdays to participate in the investigation. They were going to air, cook, have baths, wash and dry clothes just as they used to, and the times for our visit in the homes were decided by the inhabitants themselves. The investigation took place in the heating period, October 1983 - February 1984.

4. Measuring instruments

For continuous registration of air temperature and relative air humidity in kitchens we used thermohygrographs. The degree of accurancy is estimated at ± 1 ^{o}C and ± 10 per cent RH.

For measuring of the weekly average of the relative air humidity in kitchens, living-rooms, and bedrooms we used an instrument developed by The Danish Building Research Institute. It consisted of a wooden block at a size of 4.8 x 5.0 x 1.5 cm (beechwood). The measuring principle is that the wood humidity will be in balance with the relative humidity of air around the block, and the connection between the weight of the wooden block and the wood humidity will be unique. The wooden blocks were conditioned in app. 80 per cent relative air humidity at The Danish

Building Research Institute and they were weighed before they were transported to the flats in a plastic bag. After a week of exposure in the flats they were placed in plastic bags again, transported to The Danish Building Research Institute and weighed. The degree of accurancy is estimated at ± 5 per cent RH.

For measuring of the exhausted volume flows a thermic anemometer in a special measuring funnel was used. The degree of accurancy is estimated at ± 10 per cent.

5. Results

5.1 Relative air humidity

Tables 3-5 specify 1 week's average of the relative air humidities in kitchens, living-rooms, and bedrooms in all 60 flats measured scattered in the 3 buildings and the air temperatures in the kitchens. The results are divided into measure-week 1 and measure-week 2, and into reduced ventilation and maximum ventilation.

The highest relative air humidities were measured in the bedrooms. In living-rooms and kitchens the relative air humidity was practically at the same lower level.

Studying the average of the measurments for the single categories of rooms divided according to the running conditions (reduced and maximum ventilation) the relative air humidity in 15 out of 18 measure-weeks was highest in the flats with reduced ventilation compared to the flats with maximum ventilation.

5.2 Absolute air humidity

By using absolute air humidities instead of relative air humidities the humidity results can be free of influence from differences in air temperature indoors.

Tables 6-8 specify 1 week's average of the absolute air humidities in kitchens, living-rooms, and bedrooms in all 60 flats scattered in the 3 buildings and divided into measure-week 1 and measure-week 2, and into reduced ventilation and maximum ventilation.

The results of the absolute air humidities show on a whole the same picture as the results of the relative air humidities: The highest humidities are stated in the bedrooms and in the main part of the measure-weeks higher absolute air humidities in the flats were measured in dwellings with reduced ventilation.

By watching the differences between absolute air humidity inside and outside, the influence from the humidity content in the outdoor air can be removed from the figures.

Table 9 specifies the conditions outdoors during the measure-weeks.

Tables 10-12 specify the weekly average of the difference between the absolute air humidities indoors and outdoors in kitchens, living-rooms, and bedrooms in all 60 flats scattered in the 3 buildings and divided into measure-week 1 and measure-week 2, and into reduced ventilation and maximum ventilation.

Table 13 specifies the difference between the absolute air humidities indoors and outdoors for all 3 buildings in one, divided into measure-week 1 and measure-week 2, and into reduced ventilation and maximum ventilation.

It can be calculated that the absolute air humidity content in flats with reduced ventilation in half of day and night was from 8-23 per cent higher than in flats with maximum ventilation day and night.

5.3 Calculated signification of the relative air humidity

The average humidity content in the outdoor air during the 6 months of winter in Denmark is 4.4 g/kg. By inserting this figure and an average air temperature indoors of 21 ^{o}C it is possible to calculate the relative air humidities in flats with reduced ventilation and maximum ventilation day and night.

	Flats with max. ventilation	Flats with reduced ventilation
Kitchen	40 p.c. RH	41 p.c. RH
Bedroom	43 p.c. RH	45 p.c. RH
Living-room	38 p.c. RH	40 p.c. RH

6. Conclusion

The highest air humidities were measured in the bedrooms.

The relative air humidity in an average bedroom rose from 43 per cent to 45 per cent when the mechanical exhaustion was reduced to app. 40 pct. in half of day and night.

This difference in relative air humidity is significantly less than the dissipation on all 360 measurings, which form the basis of these calculations. The dissipation was app. 5.3 per cent expressed in relative air humidity.

Therefore, from an air humidity point of view, it can be said that the energy saving method, to reduce ventilation in some of the day and night hours does not give any reason for health risks in the 3 buildings from the investigation.

7. Acknowledgments

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8. Reference

SBI-rapport xx, Periodically management of ventilationplant in blocks of flats. (In Danish.)
(In preparation.)

	l/s
Kitchens > 7 m^2	20
Kitchens < 7 m^2	15
Bath- og WC-rum	15
WC-rum	10

Table 1. Demand in the Building Regulation, BR 82.

Building	1. Lundtoftegade Nørrebro	2. Stjernen Frederiksberg	3. Avedøre Stationsby
Building year	1967	1973	1974
Number of flats	744	632	750
Area of flats	40-86 m^2	53-102 m^2	57-122 m^2
Number of storeys	4-12	6-8	4
Number of flats per ventilationplant	8-24	36-48	16
Bathrooms without windows	yes	yes	yes
Inlet valves	no	yes	no
Number of flats invited to take part in the project	200	632	750
Number of positive answers	39	48	33
Exhaust air terminal device in bathroom and WC-room	valve	valve	valve
Exhaust air terminal device in kitchen	valve	valve	valve and range hood

Table 2. Data from the 3 buildings.

Building 1

Flat number	1. week relative air humidity kitchen	bedr.	liv.r.	temp. kitchen	2. week relative air humidity kitchen	bedr.	liv.r.	temp. kitchen
1	* 37,3	40,5	35,0	24,0	44,0	44,5	44,0	23,5
2	* 44,5	42,5	40,5	23,0	49,0	47,5	44,5	23,5
3	* 40,5	40,5	40,0	22,5	46,5	48,5	47,5	22,5
4	51,5	49,8	47,5	23,0	* 59,5	56,0	56,0	23,0
5	33,0	34,3	35,0	26,0	* 37,3	40,5	38,8	25,0
6	37,8	37,8	37,3	24,0	* 40,0	42,5	38,5	24,0
7	34,3	40,5	34,3	23,0				
8	* 46,3	40,0	40,5	21,5	49,8	44,5	45,3	21,5
9	* 33,0	35,5	31,5	25,0	39,5	40,5	38,5	24,5
10	* 37,8	41,0	40,0	23,5	41,0	44,5	43,0	24,5
11	* 38,5	34,3	31,5	23,0	43,5	40,5	38,8	23,0
12	* 35,0	39,5	35,5	24,0	37,3	46,8	44,5	25,5
13	* 35,0	35,5	35,0	23,0	41,0	40,0	41,0	24,0
14	44,0	44,5	35,5	23,0	* 49,8	48,5	39,5	22,5
15	34,3	41,8	36,5	23,5	* 37,3	45,8	41,0	24,0
16	36,0	37,8	37,3	23,5	* 37,8	41,0	41,0	23,5
17	35,0	35,5	33,0	23,0	* 40,5	41,0	38,5	23,0
18	36,5	41,0	38,8	24,0	* 40,5	44,5	43,0	24,0
19	38,5	44,0	45,3	23,5	* 38,8	45,3	41,8	24,5
20	38,8	43,5	37,0	24,5	* 41,8	38,8	45,8	24,0
All. flats								
Average	38,4	40,0	37,4	23,5	42,9	44,3	42,7	23,7
dissipation	4,8	3,9	4,1	1,0	5,7	4,1	4,3	1,0
Flats with max. ventil.*								
Average	38,7	38,8	36,6		42,3	44,4	42,4	
dissipation	4,4	2,9	3,7		7,0	5,0	5,3	
Flats with red. ventil.								
Average	38,2	41,0	38,0		43,5	44,1	43,0	
dissipation	5,4	4,5	4,5		4,3	3,2	3,0	

Table 3. Relative air humidity and air temperature, building 1.

Building 2

Flat number	1. week				2. week			
	relative air humidity kitchen	bedr.	liv.r.	temp. kitchen	relative air humidity kitchen	bedr.	liv.r.	temp. kitchen
1	32,0	40,0	35,5	23,0	* 30,7	37,2	32,7	23,0
2	32,8	33,8	29,8	22,0	* 29,4	31,4	29,6	22,0
3	29,3	32,0	27,0	23,0	* 28,4	29,2	24,4	23,0
4	36,0	32,8	31,0	22,0	* 31,1	28,9	29,1	22,0
5	35,0	38,5	33,8	23,0	* 33,2	34,6	30,0	22,0
6	33,0	34,3	31,0	22,0	* 30,4	31,3	26,1	22,0
7	47,5	58,3	49,8	22,0	* 44,6	57,0	43,8	21,0
8	40,5	38,8	37,0	22,0	* 33,3	39,1	31,7	21,0
9	37,8	48,0	40,5	23,0	* 35,0	43,7	39,1	22,0
10	* 33,0	31,5	29,3	22,0	29,3	28,4	25,2	23,0
11	* 35,0	39,5	32,0	24,0	30,5	35,2	28,6	24,0
12	* 27,5	33,8	29,8	23,0	24,2	30,6	27,0	24,0
13	31,0	35,5	31,5	23,0	* 26,8	31,1	26,5	24,0
14	33,8	32,8	29,3	21,0	* 31,3	29,3	25,8	21,0
15	47,5	52,5	45,3	22,0	54,6	58,4	50,8	22,0
16	32,0	37,0	32,0	23,0	30,5	36,0	28,4	23,0
17	33,0	38,5	36,5	24,0	32,6	34,3	33,7	23,0
18	38,8	46,5	41,8	22,0	37,6	35,7	35,4	22,0
19	41,0	37,8	33,8	21,0	37,6	39,6	32,2	21,0
20	35,0	38,5	34,3	21,0	32,0	30,4	35,8	21,0
All flats								
Average	35,6	39,0	34,6	22,4	33,2	36,1	31,8	22,3
dissipation	5,3	7,2	5,9	0,9	6,7	8,5	6,9	1,0
Flats with max. ventil.*								
Average	31,8	34,9	30,4		32,2	35,7	30,8	
dissipation	3,9	4,1	1,4		4,7	8,5	6,0	
Flats with red. ventil.								
Average	36,2	39,7	35,3		34,3	36,5	33,0	
dissipation	5,3	7,4	6,1		8,7	8,9	7,7	

Table 4. Relative air humidity and air temperature building 2.

Building 3

	1. week				2. week			
Flat number	relative air humidity kitchen	bedr.	liv.r.	temp. kitchen	relative air humidity kitchen	bedr.	liv.r.	temp. kitchen
1	* 29,6	33,7	28,3	22,0	37,4	39,9	35,6	21,0
2	* 33,8	42,1	34,0	23,0	36,0	44,5	37,6	22,5
3	* 27,7	33,8	28,6	21,5	29,2	36,1	31,4	22,5
4	* 26,1	34,0	26,9	23,0	28,7	37,9	28,9	23,5
5	* 26,2	33,9	33,0	24,0	28,3	35,4	34,1	23,0
6	* 33,6	41,9	32,9	21,0	39,3	49,2	37,6	21,5
7	* 34,5	38,3	35,2	20,5	36,1	38,4	37,2	20,5
8	* 26,6	29,7	25,7	24,0	28,9	31,7	27,6	24,5
9	* 25,6	29,5	25,9	19,5	25,6	29,4	26,1	20,5
10	36,2	42,3	38,1	21,0	* 33,2	41,9	34,8	20,5
11	35,5	44,8	36,9	21,5	* 33,9	44,8	36,5	22,0
12	27,8	33,5	26,0	21,0	* 30,1	33,7	28,6	20,5
13	26,0	35,7	26,5	20,5	* 29,0	38,1	28,8	20,0
14	31,5	35,4	30,4	20,5	* 30,9	42,8	31,3	20,5
15	43,5	42,7	37,6	21,5	* 34,7	44,6	35,3	21,5
16	31,7	33,3	29,9	21,5	* 31,3	33,3	29,6	21,5
17	24,5	34,2	28,1	23,0	* 26,8	35,5	28,7	22,0
18	27,2	29,0	28,5	22,0	* 27,7	29,9	28,6	21,5
19 **	31,9	40,7	33,5	20,5	36,2	45,1	39,5	21,0
20 **	23,5	30,6	26,5	24,5	24,6	31,8	27,1	23,5
All flats								
Average	30,2	36,0	30,6	21,8	31,4	38,2	32,3	21,7
dissipation	5,0	4,9	4,2	1,4	4,2	5,7	4,2	1,2
Flats with max. ventil.*								
Average	29,3	35,2	30,1		30,8	38,3	31,4	
dissipation	3,7	4,6	3,7		2,7	5,5	3,3	
Flats with red. ventil.								
Average	31,5	36,8	31,3		32,2	38,1	32,9	
dissipation	6,1	5,3	4,9		5,0	6,1	4,5	

** No mechanical exhaust

Table 5. Relative air humidity and air temperature, building 3.

Building 1

	1. week			2. week		
Flat number	Absolute humidity g/kg kitchen	bedroom	living-room	Absolute humidity g/kg kitchen	bedroom	living-room
1	* 6,9	7,5	6,5	7,9	8,0	7,9
2	* 7,8	7,4	7,1	8,8	8,6	8,0
3	* 6,9	6,9	6,8	7,9	8,2	8,1
4	9,0	8,7	8,3	* 10,4	9,8	9,8
5	6,9	7,2	7,3	* 7,3	8,0	7,6
6	7,0	7,0	6,9	* 7,4	7,9	7,1
7	6,0	7,1	6,0			
8	* 7,4	6,4	6,4	7,9	7,1	7,2
9	* 6,5	7,0	6,2	7,5	7,7	7,4
10	* 6,8	7,4	7,2	7,8	8,5	8,2
11	* 6,7	6,0	5,5	7,6	7,1	6,8
12	* 6,5	7,3	6,6	7,6	9,5	9,0
13	* 6,1	6,2	6,1	7,6	7,4	7,6
14	7,7	7,8	6,2	* 8,4	8,2	6,7
15	6,2	7,5	6,6	* 6,9	8,5	7,6
16	6,5	6,8	6,7	* 6,8	7,4	7,4
17	6,1	6,2	5,7	* 7,1	7,2	6,7
18	6,8	7,6	7,2	* 7,5	8,3	8,0
19	6,9	7,9	8,2	* 7,4	8,7	8,0
20	7,4	8,3	7,1	* 7,8	7,2	8,5
All flats						
Average	6,91	7,21	6,73	7,77	8,07	7,77
dissipation	0,71	0,69	0,72	0,79	0,77	0,78
Flats with max. ventil.*						
Average	6,84	6,90	6,49	7,70	8,12	7,74
dissipation	0,51	0,57	0,53	1,05	0,79	0,92
Flats with red. ventil.						
Average	6,95	7,46	6,93	7,84	8,01	7,80
dissipation	0,86	0,71	0,82	0,39	0,79	0,64

Table 6. Absolute air humidity, building 1.

Building 2

Flat number	1. week Absolute humidity g/kg kitchen	 bedroom	 living-room	2. week Absolute humidity g/kg kitchen	 bedroom	 living-room
1	5,6	7,0	6,6	* 5,3	6,5	5,7
2	5,4	5,5	4,9	* 4,8	5,1	4,8
3	5,1	5,6	4,7	* 4,9	5,1	4,2
4	5,9	5,4	5,1	* 5,1	4,7	4,8
5	6,1	6,7	5,9	* 5,4	5,7	4,9
6	5,4	5,6	5,1	* 5,0	5,1	4,3
7	7,8	9,6	8,2	* 6,9	8,8	6,8
8	6,6	6,4	6,1	* 5,1	6,0	4,9
9	6,6	8,4	7,1	* 5,7	7,2	6,4
10	* 5,4	5,2	4,8	5,1	4,9	4,4
11	* 6,5	7,3	5,9	5,6	6,5	5,3
12	* 4,8	5,9	5,2	4,5	5,7	5,0
13	5,4	6,2	5,5	* 5,0	5,8	4,9
14	5,2	5,0	4,5	* 4,8	4,5	4,0
15	7,8	8,6	7,4	9,0	9,6	8,4
16	5,6	6,4	5,6	5,3	6,3	4,9
17	6,1	7,1	6,8	5,7	6,0	5,9
18	6,4	7,6	6,9	6,2	5,9	5,8
19	6,3	5,8	5,2	5,8	6,1	5,0
20	5,4	5,9	5,3	4,9	4,7	5,5
All flats Average dissipation	 5,97 0,82	 6,56 1,24	 5,84 1,02	 5,51 0,99	 6,01 1,30	 5,30 1,02
Flats with max. ventil.* Average dissipation	 5,57 0,86	 6,13 1,07	 5,30 0,56	 5,27 0,60	 5,86 1,26	 5,06 0,89
Flats with red. ventil. Average dissipation	 6,04 0,82	 6,64 1,28	 5,94 1,06	 5,79 1,31	 6,19 1,41	 5,58 1,16

Table 7. Absolute air humidity, building 2.

Building 3

	1. week			2. week		
Flat number	Absolute humidity g/kg kitchen	bedroom	living-room	Absolute humidity g/kg kitchen	bedroom	living-room
1	* 4,8	5,5	4,6	5,8	6,2	5,5
2	* 5,9	7,3	5,9	6,1	7,5	6,4
3	* 4,4	5,4	4,6	5,0	6,2	5,4
4	* 4,5	5,9	4,7	5,1	6,8	5,2
5	* 4,9	6,4	6,2	5,0	6,2	6,0
6	* 5,2	6,5	5,1	6,3	7,8	6,0
7	* 5,2	5,7	5,3	5,4	5,7	5,6
8	* 4,9	5,5	4,7	5,5	6,0	5,3
9	* 3,6	4,1	3,6	3,8	4,4	3,9
10	5,6	6,6	5,9	* 5,0	6,3	5,3
11	5,6	7,1	5,9	* 5,6	7,4	6,0
12	4,3	5,2	4,0	* 4,4	5,0	4,2
13	3,9	5,4	4,0	* 4,2	5,6	4,2
14	4,7	5,3	4,5	* 4,6	6,4	4,7
15	6,9	6,8	6,0	* 5,5	7,1	5,6
16	5,0	5,3	4,7	* 5,0	5,3	4,7
17	4,3	6,0	4,9	* 4,4	5,9	4,8
18	4,4	4,7	4,7	* 4,4	4,8	4,6
19 **	4,8	6,2	5,1	5,6	7,1	6,2
20 **	4,5	5,8	5,0	4,5	5,8	4,9
All flats						
Average	4,89	5,82	4,96	5,06	6,14	5,19
dissipation	0,78	0,84	0,76	0,68	0,94	0,71
Flats with max. ventil.*						
Average	4,82	5,81	4,97	4,79	5,98	4,90
dissipation	0,64	0,89	0,77	0,51	0,90	0,61
Flats with red. ventil.						
Average	4,97	5,82	4,96	5,33	6,31	5,48
dissipation	0,93	0,84	0,79	0,74	1,00	0,71

** No mechanical ventilation.

Table 8. Absolute air humidity, building 3.

	Humidity content in outd. air g/kg Building		
	1	2	3
Measure-week 1	5,5	4,1	2,8
Measure week 2	6,2	3,2	3,5

Table 9. Humidity content in outdoor air.

Building 1

Flat number	1. week Absolute humidity g/kg kitchen	bedroom	living-room	2. week Absolute humidity g/kg kitchen	bedroom	living-room
1	* 1,4	2,0	1,0	1,7	1,8	1,7
2	* 2,3	1,9	1,6	2,6	2,4	1,8
3	* 1,4	1,4	1,3	1,7	2,0	1,9
4	3,5	3,2	2,8	* 4,2	3,6	3,6
5	1,4	1,7	1,8	* 1,1	1,8	1,4
6	1,5	1,5	1,4	* 1,2	1,7	0,9
7	0,5	1,6	0,5			
8	* 1,9	0,9	0,9	1,7	0,9	1,0
9	* 1,0	1,5	0,7	1,3	1,5	1,2
10	* 1,3	1,9	1,7	1,6	2,3	2,0
11	* 1,2	0,5	0	1,4	0,9	0,6
12	* 1,0	1,8	1,1	1,4	3,3	2,8
13	* 0,6	0,7	0,6	1,4	1,2	1,4
14	2,2	2,3	0,7	* 2,2	2,0	0,5
15	0,7	2,0	1,1	* 0,7	2,3	1,4
16	1,0	1,3	1,2	* 0,6	1,2	1,2
17	0,6	0,7	0,2	* 0,9	1,0	0,5
18	1,3	2,1	1,7	* 1,3	2,1	1,8
19	1,4	2,4	2,7	* 1,2	2,5	1,8
20	1,9	2,8	1,6	* 1,6	1,0	2,3
All flats						
Average	1,41	1,71	1,23	1,57	1,87	1,57
dissipation	0,71	0,69	0,72	0,79	0,77	0,78
Flats with max. ventil.*						
Average	1,34	1,40	0,99	1,50	1,92	1,54
dissipation	0,51	0,57	0,53	1,05	0,79	0,92
Flats with red. ventil.						
Average	1,45	1,96	1,43	1,64	1,81	1,60
dissipation	0,86	0,71	0,82	0,39	0,79	0,64

Table 10. Difference between absolute air humidity indoors and outdoors, building 1.

Building 2

	1. week			2. week		
Flat number	Absolute humidity g/kg kitchen	bedroom	living-room	Absolute humidity g/kg kitchen	bedroom	living-room
1	1,5	2,9	2,5	* 2,1	3,3	2,5
2	1,3	1,4	0,8	* 1,6	1,9	1,6
3	1,0	1,5	0,6	* 1,7	1,9	1,0
4	1,8	1,3	1,0	* 1,9	1,5	1,6
5	2,0	2,6	1,8	* 2,2	2,5	1,7
6	1,3	1,5	1,0	* 1,8	1,9	1,1
7	3,7	5,5	4,1	* 3,7	5,6	3,6
8	2,5	2,3	2,0	* 1,9	2,8	1,7
9	2,5	4,3	3,0	* 2,5	4,0	3,2
10	* 1,3	1,1	0,7	1,9	1,7	1,2
11	* 2,4	3,2	1,8	2,4	3,3	2,1
12	* 0,7	1,8	1,1	1,3	2,5	1,8
13	1,3	2,1	1,4	* 1,8	2,6	1,7
14	1,1	0,9	0,4	* 1,6	1,3	0,8
15	3,7	4,5	3,3	5,8	6,4	5,2
16	1,5	2,3	1,5	2,1	3,1	1,7
17	2,0	3,0	2,7	2,5	2,8	2,7
18	2,3	3,5	2,8	3,0	2,7	2,6
19	2,2	1,7	1,1	2,6	2,9	1,8
20	1,3	1,8	1,2	1,7	1,5	2,3
All flats						
Average	1,87	2,46	1,74	2,31	2,81	2,10
dissipation	0,82	1,24	1,02	0,99	1,30	1,02
Flats with max. ventil.						
Average	1,47	2,03	1,20	2,07	2,66	1,86
dissipation	0,86	1,07	0,56	0,60	1,26	0,89
Flats with red. ventil.						
Average	1,94	2,54	1,84	2,59	2,99	2,38
dissipation	0,82	1,28	1,06	1,31	1,41	1,16

Table 11. Difference between absolute air humidity indoors and outdoors, building 2.

Building 3

	1. week			2. week		
Flat number	Diff. between absolute humidity in-out, g/kg kitchen	bedroom	living-room	Diff. between absolute humidity in-out, g/kg kitchen	bedroom	living-room
1	* 2,0	2,7	1,8	2,3	2,7	2,0
2	* 3,1	4,5	3,1	2,6	4,0	2,9
3	* 1,6	2,6	1,8	1,5	2,7	1,9
4	* 1,7	3,1	1,9	1,6	3,3	1,7
5	* 2,1	3,6	3,4	1,5	2,7	2,5
6	* 2,4	3,7	2,3	2,8	4,3	2,5
7	* 2,4	2,9	2,5	1,9	2,2	2,1
8	* 2,1	2,7	1,9	2,0	2,5	1,8
9	* 0,8	1,3	0,8	0,3	0,9	0,4
10	2,8	3,8	3,1	* 1,5	2,8	1,8
11	2,8	4,3	3,1	* 2,1	3,9	2,5
12	1,5	2,4	1,2	* 0,9	1,5	0,7
13	1,1	2,6	1,2	* 0,7	2,1	0,7
14	1,9	2,5	1,7	* 1,1	2,9	1,2
15	4,1	4,0	3,2	* 2,0	3,6	2,1
16	2,2	2,5	1,9	* 1,5	1,8	1,2
17	1.5	3.2	2,1	* 0,9	2,4	1,3
18	1,6	1,9	1,9	* 0,9	1,3	1,1
19 **	2,0	3,4	2,3	2,1	3,6	2,7
20 **	1,7	3,0	2,2	1,0	2,3	1,4
All flats Average	2,09	3,02	2,16	1,56	2,64	1,69
dissipation	0,78	0,84	0,76	0,68	0,94	0,71
Flats with max. ventil.* Average	2,02	3,01	2,17	1,29	2,48	1,40
dissipation	0,64	0,89	0,77	0,51	0,90	0,61
Flats with red. ventil. Average	2,17	3,02	2,16	1,83	2,81	1,98
dissipation	0,93	0,84	0,79	0,74	1,00	0,71

** No mechanical ventilation.

Table 12. Difference between absolute air humidity indoors and outdoors, building 3.

Building 1, 2 and 3

	1. week			2. week		
Flat number	Diff. between absolute humidity in-out, g/kg			Diff. between absolute humidity in-out, g/kg		
	kitchen	bedroom	living-room	kitchen	bedroom	living-room
All flats						
Average	1,78	2,37	1,69	1,82	2,44	1,79
dissipation	0,81	1,08	0,92	0,90	1,10	0,87
Flats with max. ventil.*						
Average	1,65	2,18	1,52	1,65	2,36	1,62
dissipation	0,67	1,07	0,84	0,81	1,03	0,83
Flats with red. ventil.						
Average	1,85	2,48	1,79	2,02	2,54	1,99
dissipation	0,88	1,09	0,95	0,96	1,18	0,89

Table 13. Difference between absolute air humidity outdoors and indoors, all 3 buildings.

OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

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PAPER S.3

A DETAILED STATISTICAL ANALYSIS OF WINDOW USE AND ITS EFFECT ON THE VENTILATION RATE IN 2400 BELGIAN SOCIAL HOUSES

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SYNOPSIS

A large inquiry campaign began in 1985 on 100 social housing estates and 2,334 families were visited.
The housing estates were selected according to their age, location, type of building (dwelling/apartment) and heating system.

The main purpose of this paper is to explore the data received concerning window use in order to find the effect of the inhabitants on the ventilation rate. The summertime and wintertime situation was analysed and differences between individual dwellings and apartments were also investigated.

The results of this study can be summarized as follows :
- a rather good description of window use in Belgian social houses was achieved
- the impact of window use on the ventilation rate is estimated.

1. INTRODUCTION

A large inquiry campaign was conducted on some hundred social housing estates in Belgium. A total number of 2,334 families (1,115 individual dwellings and 1,219 apartments) were visited between January 1985 and November 1985. The major aims of the study were :
- to give a representative overview of building damage in the housing stock of the National Housing Society and to give indications for renovation opportunities (229,000 dwellings and apartments)
- to make a statistical representative database on inhabitants' behaviour with regard to ventilation and energy use.

This paper describes only a limited part of the data in relation to inhabitants' behaviour.

Firstly, a short overview of results concerning the motivation for opening and closing windows and doors is given. The major part then deals with the use of windows and doors in winter and summertime, i.e. position, frequency and duration of opening, and time of day. A combination of these data, with assumptions concerning air flow rates through open windows, have led to the estimation of air change rates.

2. MOTIVATION FOR OPENING AND CLOSING WINDOWS AND DOORS

People were asked to indicate the importance of several reasons for opening and closing windows. Four answers were possible. The possible answers and the percentages are given in Tables 1 and 2.

	Very important (3)	Impor-tant (2)	Less important (1)	Not important (0)	Average
-to air	53	42	3	2	**2.47**
-to remove bad smells	40	41	6	13	**2.08**
-to avoid condensation	17	42	14	27	**1.49**
-to remove smoke	13	27	18	41	**1.11**
-to renew stained air by heating	10	26	23	40	**1.05**
- to reduce temperature	6	20	23	49	**0.81**

Table 1 - Reasons for opening windows (% of answers).
The last column gives the weighted average of the 4 answers; where
- very important = 3
- important = 2
- less important = 1
- not important = 0.

	Very important (3)	Important (2)	Less important (1)	Not important (0)	Average
-to maintain the inside temperature	64	31	2	2	**2.56**
-to protect against bad weather	37	43	5	15	**2.02**
-to avoid draught	34	42	9	16	**1.95**
-to preserve safety	34	31	10	24	**1.74**
-to avoid outside pollution	16	32	24	27	**1.36**
-to preserve privacy	13	28	25	34	**1.20**
-to avoid outside noise	14	24	25	37	**1.15**

Table 2 - Reasons for closing windows or to hold them closed (% of answers, total of each line is 100 %).
The last column gives the weighted average of the 4 answers; where :

- very important = 3
- important = 2
- less important = 1
- not important = 0.

3. HOW DO PEOPLE USE WINDOWS ?

3.1. Basic analysis

Four questions were asked with regard to the window use in different rooms. A total of 8,955 answers for wintertime use and 9,323 for summertime use were given.

3.1.1. **Question 1 : Position of the window**

Table 3 gives three possibilities and the number of answers (use in winter time and use in summertime) in percentage and in absolute figures (between brackets).

Answer	WINTER	SUMMER
- Window never open	**27** (2,460)	**9** (880)
- Window ajar	**53** (4,700)	**33** (3,090)
- Window wide open	**20** (1,790)	**57** (5,350)

Table 3 - Number of rooms with such window use
(Percentage and absolute number)

A significant difference between summer and winter exists : 1 of the 4 rooms is never ventilated in winter, while this figure becomes only 1 of the 10 rooms in summer. Preference is given to windows ajar in winter and wide open in summer.

3.1.2. **Question 2 : How many times do you open the window ?**

Table 4 gives the results. The percentages are indicated with reference to the number of rooms where windows and doors are opened.

Answer	WINTER	SUMMER
- Several times a day	**6** (380)	**12** (850)
- Once a day	**81** (5,140)	**82** (5,950)
- Several times a week	**7** (420)	**4** (290)
- Once a week	**6** (400)	**3** (190)

Table 4 - Frequency of window opening (%)

Interpretation : 80 % of windows are ventilated once a day. No significant difference exists between summer and wintertime.

3.1.3. **Question 3 : What is the average opening time ?**

Four answers were possible. "Continuously" is related to the fourth question.

Answer	WINTER	SUMMER
- A few minutes	**21** (1,380)	**3** (280)
- Less than one hour	**46** (2,990)	**8** (680)
- Several hours	**12** (810)	**21** (1,760)
- Continuously during the period indicated in Table 6	**21** (1,340)	**68** (5,740)

Table 5 - Average opening time (%)

Interpretation : As one can expect, the opening time in winter is rather short; in 66% of the cases less than 1 hour.
In summertime, 90 % of the windows are open at least several hours a day.

3.1.4. **Question 4 : At what time of the day are the rooms ventilated ?**

Nine answers were possible (see Table 6)

Answer	WINTER	SUMMER
- Early in the morning	3 (300)	2 (220)
- In the morning	32 (2,860)	6 (540)
- At noon	4 (400)	2 (180)
- In the afternoon	5 (480)	3 (260)
- In the early evening	1 (100)	0 (30)
- In the evening	2 (230)	1 (110)
- During the day	19 (1,740)	58 (5,490)
- At night	29 (2,640)	11 (1,070)
- Day and night	4 (330)	16 (1,540)

Table 6 - Distribution (in %) of time of the day for ventilating the room.

In the case of wintertime, the morning period is frequently answered, contrary to summertime where preference is given to "during the day".

Remark :
Earlier studies showed that the reliability of the information given by inhabitants can be doubtful. One should therefore be careful and pay more attention to relative differences than to absolute figures.

3.2. <u>Detailed analyses of window use as a function of the type of room</u>

3.2.1. **How many windows/doors are opened and in which position ?**

Table 7 gives an overview of the distribution of the answers for six different rooms and for the whole dwelling. A separation between individual dwellings and apartments has also been made.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
1. **Window never open**						
- living room	52	57	46	18	22	14
- kitchen	26	33	19	6	7	4
- bathroom	31	27	42	12	9	17
- bedroom 1	8	8	7	3	2	3
- bedroom 2	19	16	22	9	7	10
- bedroom 3	20	20	20	7	6	10
- entire house	**27**	**29**	**25**	**9**	**10**	**9**
2. **Window ajar**						
- living room	37	29	46	23	18	28
- kitchen	62	50	73	40	28	51
- bathroom	50	48	55	43	37	57
- bedroom 1	66	57	72	38	27	46
- bedroom 2	55	48	61	31	20	40
- bedroom 3	50	49	53	27	23	36
- entire house	**53**	**45**	**62**	**33**	**26**	**42**
3. **Window wide open**						
- living room	11	14	7	59	60	58
- kitchen	12	17	7	55	65	45
- bathroom	19	25	3	45	54	25
- bedroom 1	27	35	20	60	71	51
- bedroom 2	27	36	17	61	73	50
- bedroom 3	30	31	27	66	71	53
- entire house	**20**	**25**	**13**	**57**	**64**	**50**

<u>Table 7</u> - Number of rooms with this window use (%).

Interpretation

- For the entire house

  - There is no significant difference between apartments and dwellings with regard to the number of rooms which are never ventilated.
  - A significant difference exists in preference of window position : preference is given to the position "ajar" for apartments :

    wintertime : almost 85 % (62 / (62+13)) of the windows are opened "ajar" in the case of apartments, while 65 % (45 / (45+25)) was the case for individual dwellings.

    summertime : 45 % of the windows are opened "ajar" for apartments, 30 % for individual dwellings.

- For the individual rooms

  - The number of living rooms which are never ventilated in wintertime is much higher than the average figure for the entire house : 52 % against 27 %.

    57 % of the living rooms in individual dwellings are never ventilated.
  - The bedrooms are more ventilated than the average room.

    90 % of all the principal bedrooms are ventilated in wintertime.
  - The window position "wide open" is very seldom used in wintertime in the case of living rooms, kitchens and bathrooms of apartments.

3.2.2. **Estimation of opening times**

The collected information did not give us direct information about the duration of ventilation, and this information is important for calculations.
The answers were therefore translated into duration times.
It is evident that such translation is rather subjective.

ASSUMPTIONS :

- Frequency

  Several times a day/a week → we suppose twice a week

- Duration time

. a few minutes	→	0.25 hour	
. less than 1 hour	→	0.75 hour	
. several hours	→	2 hours	
. continuously	→	early in the morning	= 2 hours
		in the morning	= 2 hours
		at noon	= 3 hours
		in the afternoon	= 3 hours
		in the early evening	= 3 hours
		in the evening	= 3 hours
		during the day	= 10 hours
		at night	= 10 hours
		day and night	= 24 hours

Table 8 gives all the results.

Remark : the weighted average opening time has been calculated as follows :

ex. : living room, all houses :

Table 7 : - 52 % are never opened
- 37 % are opened ajar
- 11 % are wide open.

Table 8 : - average opening time ajar = 1,0 h/day
- average opening time wide open = 1,3 h/day.

→ weighted average opening time =
(0,52 x 0 + 0,37 x 1 + 0,11 x 1,3) h/day =
0,51 h/day → 0,5 h/day.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
1. Weighted average opening time for all the rooms						
- living room	0.5	0.4	0.7	6	5	7
- kitchen	1.1	0.9	1.4	7.0	6	7.5
- bathroom	1.4	1.6	0.9	7.0	7.5	6
- bedroom 1	3.8	4.0	3.7	11.5	11.5	11.5
- bedroom 2	2.9	2.9	2.9	10.0	10	10
- bedroom 3	2.4	2.2	2.8	9.5	9.5	10.5
- **entire house**	**2.0**	**2.0**	**2.1**	**8.5**	**8**	**9**
2. Window ajar						
- living room	1.0	0.8	1.2	6	5	6.5
- kitchen	1.5	1.2	1.8	6.5	6.5	6.5
- bathroom	2.1	2.5	1.5	7	7.5	6.5
- bedroom 1	4.1	4.5	3.8	12	12.5	12
- bedroom 2	3.4	3.3	3.5	10.5	10.5	10.5
- bedroom 3	2.7	2.7	2.7	10.5	8.5	13.5
- **entire house**	**2.8**	**2.9**	**2.6**	**9**	**9**	**9**
3. Window wide open						
- living room	1.3	1.0	1.8	8	6.5	9.0
- kitchen	1.7	1.6	1.9	8	6.5	9.5
- bathroom	1.6	1.6	1.3	8.5	8.5	9.0
- bedroom 1	4.3	4.2	4.5	12	11.5	12
- bedroom 2	3.7	3.6	4.1	11	11	11
- bedroom 3	3.4	2.8	5.1	10.5	10.5	11
- **entire house**	**3.0**	**2.6**	**3.8**	**9.5**	**9**	**10.5**

Table 8 - Average duration time of window opening as function of several parameters (hours/day)

Interpretation

Table 9 gives the results for the entire house.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
Window ajar	2.8(53)	2.9(45)	2.6(62)	9 (33)	9 (26)	9 (42)
Window wide open	3.0(20)	2.6(25)	3.8(13)	9.5(57)	9 (64)	10.5(50)
Weighted average	**2.0**	**2.0**	**2.1**	**8.5**	**8**	**9**

Table 9 - Average opening time for the 2 window positions and weighted average (the figures between brackets are the frequency of occurance - %) (hours/day).

- The average opening time of all the windows in a house is 2 hours a day in wintertime and 8 hours a day in summertime.
- Higher values are found for bedrooms and lower values for living rooms and kitchens.
- The opening times for windows "ajar" are more or less the same as for windows "wide open".

- The average opening time for the whole house is 8 % in wintertime and about 35 % in summertime.
  These values can be compared with the formulae of Lyberg [1] and De Gids [2]

Lyberg : $H.\Delta T = C^{te} = 180 \ldots 260$ (hyperbolic)

De Gids : $H = A + B\,T$

where $A \simeq 10$ and $B \simeq 0.65$

H = percentage of open windows (%)

T = external temperature (°C)

ΔT = temperature difference between inside and outside = $T_i - T_e$ (i)

For Belgium :

T_i = 18°C

T_e = 2°C (average temperature January)

= 15°C (average temperature Summer)

or De Gids : H = 11 % (wintertime) and 20 % (summertime)

Lyberg : H = 11 to 16 % (wintertime)

Our data for wintertime are lower than the results obtained from the 2 formulae; for summertime these data are higher than the figure of De Gids. (the formulae of Lyberg are not viable for small values of ΔT).

3.2.3. Estimation of the increase in ventilation rates due to window use

- An estimation of the effect of inhabitants' behaviour on the ventilation rate is possible.
  Let us suppose :
  - air flow rates through an open window :
    - window ajar (6 cm) : 50 to 150 m^3/h (Knöbel) [3]
    - window wide open (0.5 m^2) : 200 to 300 m^3/h (Pfaff) [4]

  Rem. : we have supposed the same airflows in wintertime and summertime taking into account the high uncertainty of the assumed airflow rates
  - dwelling/apartment - volume : 200 m^3.

The application of this assumption to the information obtained for all the rooms allows an estimation of the increase in ventilation rate due to the occupants n_{occ} :

$$n_{occ} = \left(\frac{\sum \text{TIME} \times Q_{W,min}}{24 \times \text{VOL}} + \frac{\sum \text{TIME} \times Q_{W,max}}{24 \times \text{VOL}} \right) / 2$$

where :

n_{occ} : increase in ventilation rate due to occupants (ac/h)

$\sum$: addition for all the rooms

TIME : estimated duration of open windows (h/day)

Q_W : estimated air flow through open windows (m^3/h) (ajar/wide open)

max : maximum air flow (150 m^3 for ajar and 300 m^3 for wide open)

min : minimum air flow (50 m^3 for ajar and 200 m^3 for wide open)

VOL : air volume of the house (m^3)

Table 10 gives the average values and median values.

	Dwellings+apartm.		Dwellings		Apartments	
	mean	median	mean	median	mean	median
WINTER	0,26	0,10	0,31	0,14	0,21	0,09
SUMMER	1,5	1,2	1,7	1,3	1,3	1,0

Table 10 - Mean and median values for n_{occ} (ac/h).

A distribution of the increase in ventilation rates is given in Figs. 1 to 3.

Interpretation

- The influence of the window use on the ventilation rate can be analysed by using mean values or median values.
  Table 10 shows that there exists a significant difference between them.
  - mean : weighted average of all the values
  - median : the average value of the samples when arranged in order of magnitude.

- The mean value for n_{occ} in winter is 0,26 ac/h; this means that window use increases on average with a ventilation rate of 0,26 ac/h. The median, which is 0,10 ac/h, means that n_{occ} is less than 0,10 ac/h, in 50 % of all the cases.

- Practical conclusion :
  - the window use in winter signifies for 50 % of the houses an increase in ventilation rate of less than 0,10 ac/h.
  - a very significant difference for n_{occ} between dwellings and apartments exists : 0,31 ac/h versus 0,21 ac/h.
    This is due to the fact that windows ajar are much more common in apartments than in dwellings.
    This result might be somewhat misleading because it is clear that the air flow through an open window in an apartment building at the 5th floor is higher than the same open window at street level in a dwelling.
  - the results in summertime indicate that n_{occ} is between 1 and 1,5 ac/h.
  - Table 11 gives the percentage of families where n_{occ} is higher in winter than the indicated values.

	> 0,25	> 0,50	> 0,70	> 1,00
All houses	28	15	11	7
Dwellings	32	17	13	9
Apartments	23	12	8	5

Table 11 - % of families with n_{occ} in winter above the indicated value (ac/h).

3.2.4. **Practical calculation data**

The rather wide variation in figures does not allow us to realize a very clear formula for the expression of window use. The following 3 tables try to reflect the main trends in the results.

		WINTER			SUMMER		
		Dwell.	Average	Ap.	Dwell.	Average	Ap.
NEVER	whole house		30			10	
	living room	+	50	-		20	-
	bedrooms		15			5	
AJAR	whole house	-	50	++	-	30	++
	living room	--	40	+		35	
	bedrooms	-	55	+		35	
WIDE OPEN	whole house	+	20	-	++	55	-
	living room	+	10	-	++	60	--
	bedrooms	+	30	-	++	60	--

Table 12 - Simplified table for average window use (in %)

+ = 5 to 10 % more than average

++ = more than 10 % above average

- = 5 to 10 % less than average

-- = more than 10 % beneath average.

		WINTER			SUMMER		
		Dwell.	Average	Ap.	Dwell.	Average	Ap.
AVERAGE FOR ALL ROOMS	whole house living room bedrooms	- (living room)	2 0.5 3	+ (living room)		8 6 10	
ROOM WITH OPEN WINDOWS	whole house living room bedrooms	- (living room)	3 1 4.0	+ (living room)			

Table 13 - Simplified table for average opening time of windows (hours/day) + = at least 20 % higher than average

− = at least 20 % less than average

	WINTER		SUMMER	
	AJAR	WIDE OPEN	AJAR	WIDE OPEN
Less than 15 min.	4	2	1	1
15 to 30 minutes	10	2	1	1
30 min. to 1 hour	20	8	4	4
1 to 3 hours	8	4	8	8
3 to 6 hours	1	1	1	4
6 to 12 hours	4	2	15	30
More than 12 hours	2	2	4	10
Not ventilated	30		10	

Table 14 - Simplified table for distribution estimation of window opening times (% of all the rooms).

4. CONCLUSION

The main conclusions of this study are :

- some 30 % of all the windows were never opened in wintertime and some 10 % in summertime. Higher values are found for the living room and lower ones for the bedrooms.

- There is a preference for the position "ajar" in wintertime and "wide open" in summertime. In apartments the position "ajar" occurs more frequently.

- The average opening time for all the windows is some 2 hours in winter and some 8 hours in summer.

- This behaviour data in combination with a few assumptions lead to an estimated average increase in the ventilation rate for wintertime of 0.25 ac/h with somewhat higher values for dwellings and somewhat lower values in apartments.
  However, for 50 % of the families this increase is below 0,1 ac/h.

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Finally our gratitude goes to Mrs. M. Olislaegers who transformed our notes into camera-ready copy.

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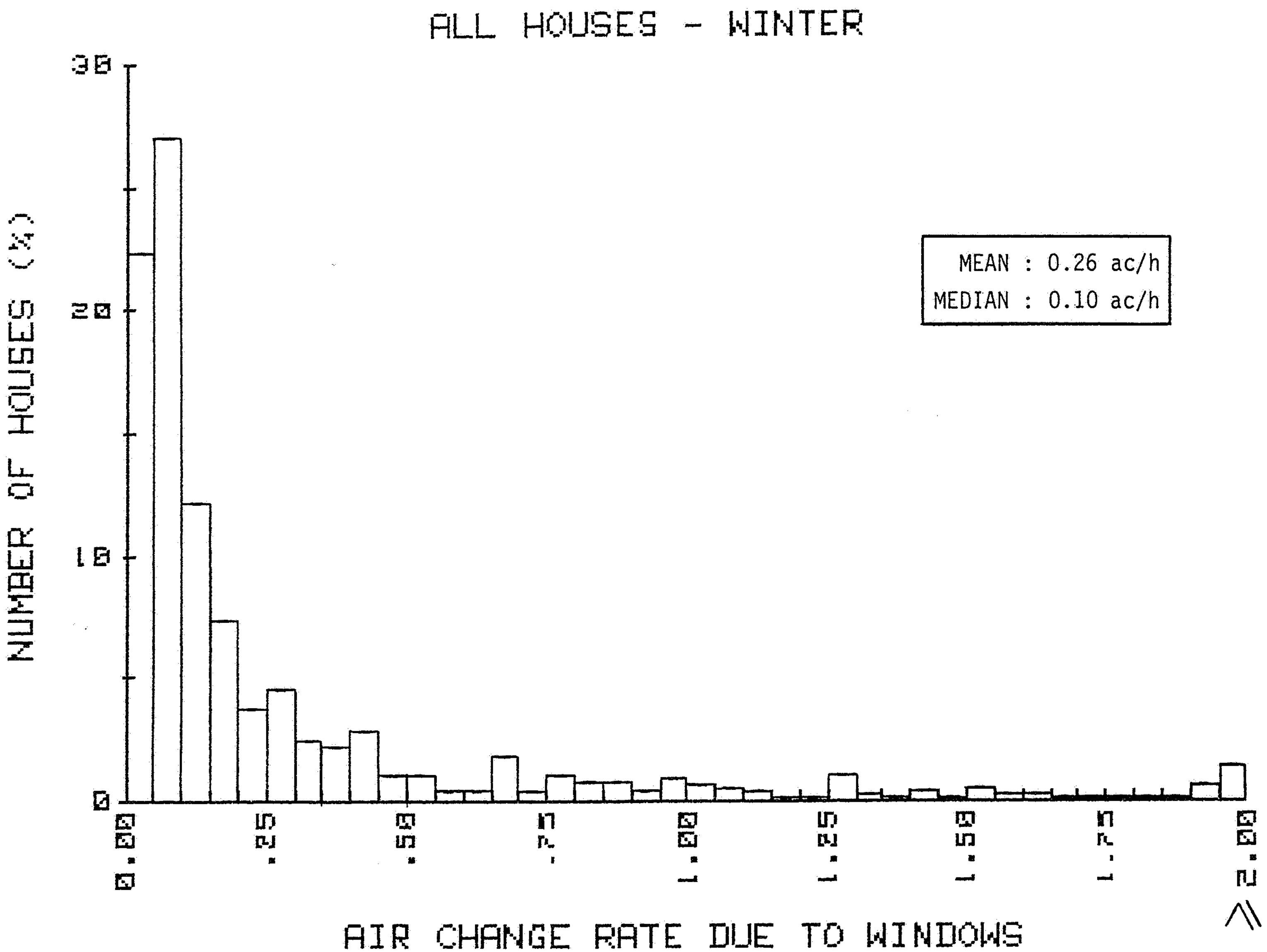

Fig. 1 : distribution of n_{occ} for dwellings and apartments (ac/h)

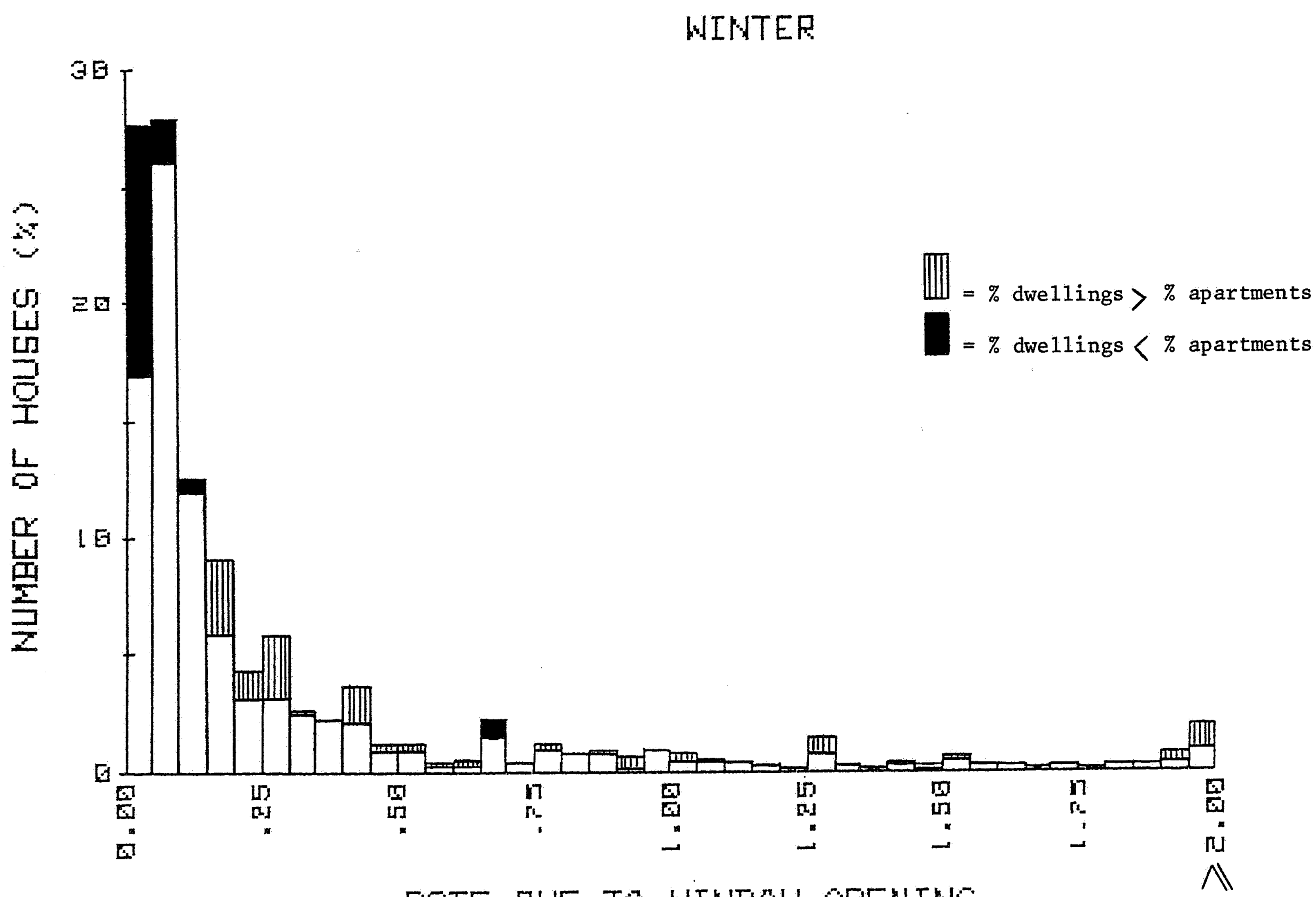

Fig. 2 : distribution of n_{occ}

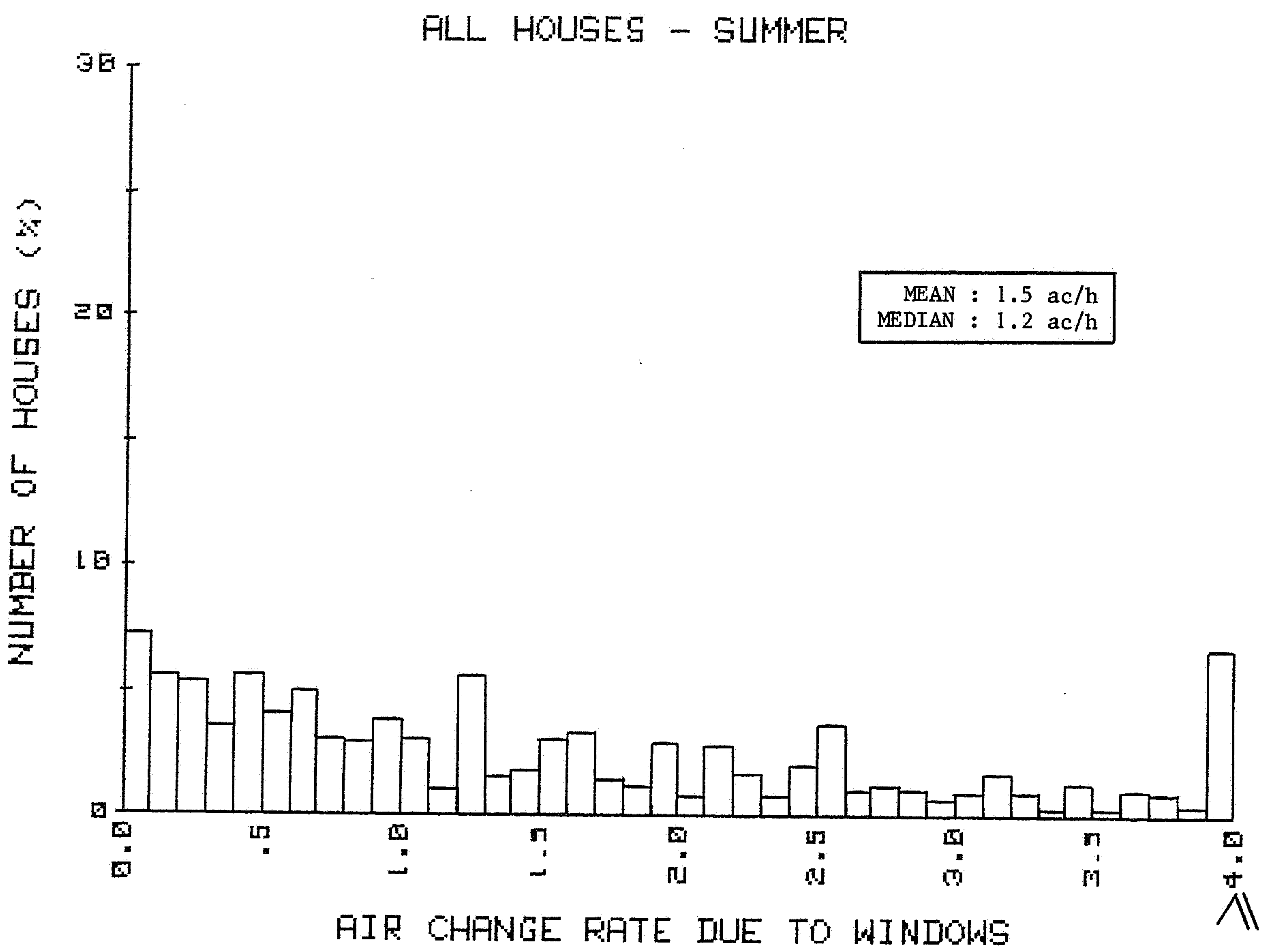

Fig. 3 : distribution of n_{occ} for dwellings and apartments (ac/h)

OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
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PAPER S.4

EFFECT OF INSTRUCTIONS TO INHABITANTS ON THEIR BEHAVIOUR

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1. Introduction

1.1. General

Within the framework of the International Energy Agency (IEA) Annex VIII , "Inhabitants Behaviour with Regard to Ventilation" an investigation has been carried out on the use of windows in an apartment building in Schiedam. The measurements have been done by the TNO Division of Technology for Society. They started in November 1984 and stopped in May 1986.
Three inquiries and diaries have been set up in the two heating seasons and the summer period to get additional information from the dwellers.
In the 6th AIC conference [1] paper 20 dealt with the first heating season of this project.
As the project and analysis have to be finished in March 1987 the contents of this paper are only preliminary results.

1.2. Purpose

Determination of:

1. window behaviour, relation to climatic conditions
2. energyloss due to open windows
3. motives for opening windows
4. changes in behaviour by information and instruction to the inhabitant.

1.3. Building and meteo

The apartment building is situated in Schiedam which is at the west side of Rotterdam , some 20 kilometres from the coast of the North Sea in the Nether lands. The building is surrounded by similar apartment buildings except for the North to East side. The mean temperature in the heating season, which is approximately 200 days, is 5 degree Centigrade. The mean wind velocity is 5 m/s with a prevailing West direction except for the cold periods in winter (-15 to -5 degree C.) and also the hot periods in summer (above 20 degree C.) then the wind direction is East, coming from the land climate region of the continent of Europe. The building has 10 floors and 14 dwellings on one row per floor. In the middle of the building there is a staircase and elevators, these give access to the gallery, an open corridor hanging on the outside of the building just like

the balcony on the other side. The frontdoors of the dwellings , as seen from the wind and stack pressure point of view, are only linked to outside air and not to the thermal pressure in the staircase. Therefore the only difference between low and high floors is the difference in wind exposure and the thermal height of the natural ventilation ducts. However this last factor is largely eliminated by the frictionloss in the ducts. These ducts are meant to exhaust air from WC,bathroom and kitchen, but frequently they transport spoiled exhaust air from one dwelling, as supply air to another dwelling on a higer or lower floor. This is due to the fact that the ducts are vertically combined. The first 5 floors have 3 main ducts per vertical row of apartments, and the upper floors also have 3 main ducts. Every single duct, for example from the kitchen, goes up approximately 3 metres and then enters the main duct. These 3 metres have been thought to give a stack effect strong enough to deal with the wind pressure differences from floor to floor. But one can imagine that an open leeward window on one floor and a windward one on another can overrule 3 metres thermal pressure very easily. Since 1975 this system is no longer allowed in new buildings as it gives many complaints about the spread of odour. The mean duct flowrate is about 0,006 m3/s (20 m3/hour) per single duct, 0,017 m3/s (60 m3/hour) per dwelling.
A lot of these buildings in the Netherlands still exist and for reasons of easy access from the outside during the instrumentation this building was choosen.
80 of the 140 apartments have been instrumented. Every apartment has 16 windows and outside doors, 6 windows and a frontdoor on the gallery side and 8 windows and a balcony door on the balcony facade. Above every large casement window (area 0.9 m2) there is a smaller ventlight or pivoted flap window. The total number of windows and outside doors is 80 * 16 = 1280.

1.4. Amount of data

The measurements started on 29th November 1984 and stopped on 12 May 1986. This results in a total period of 529 days, however on 62 days due to several failures no data has been measured. There remain 467 days with all window positions with a 15 to 20 second time resolution.
On cold winterdays one or two front doors closed so badly that in the closed position the part with the sensor was still more than 15 mm away from the normal closed position, which caused in some way a false result. A few kitchen windows also suffered this phenomenon.

1.5. Instruction

In November 1986 before the second winter period all 80 inhabitants had a written example how to make proper use of the windows. About 20 inhabitants were selected by means of their measured window use and visited personally. In these visits we tried to give some information about the energyloss by a large window open for more than 8 hour a day, and also the risks of not opening windows. In all instructions and talks we tried to leave the choice to the inhabitant more by gentle hints than severe rules.
The written instruction had the following form:

Example for the use of windows and doors at normal weather in Spring/Autumn and Winter.

Bedrooms

Day:
Large window open 20 minutes
(at putting the bedclothes in order)
Ventlight whole day ajar (1 cm)

Night:
Ventlight half open.

Livingroom

When one is in the room:
Either: 2 persons -ventlight half.
4 persons -ventlight full.
or: livingroom inner door open and some windows in bedrooms and kitchen open.

Night (or no one in the room):
Windows closed, except with (more) smokers, then a ventlight open.

Kitchen

During cooking:
Windows as one wishes

After cooking:
Either: ventlight 20 minutes open
or: casement window 5 minutes open followed by an open ventlight

Shower

Inner door open for some hours on 10 cm after use of the shower.

Remark:
At strong wind and cold periods windows can be open for a shorter time and less wide.
At weak wind and warmer periods windows can be open for a longer time and more wide.

2. Results

2.1. Temperature

As stated earlier and by many others, temperature is the most predominant variable in window use. In the first paper [1] we found a linear relation between the number of all open windows together and the outside temperature both based on weekly means. Most wind and rain variance is lost by taking a weekly mean and therefore the correlation with temperature was very high (0.96). Now we looked more at daily mean values for the different windows and left the idea of linear temperature relations. In figure 1 all 467 daily mean values for the balcony door have been plotted against the outside temperature. As can be seen the door is not frequently used below 8 degree C. This door is used for ventilation in the livingroom and also allows inhabitants to keep in touch with outside. Above 10 degree C. a lot of doors are opened. Other windows just show the opposite behaviour with already an increase at very low temperature and stabilising (because there are no more windows practically available) at high temperature.
One could say that large windows tend more to the balconydoor and small ventlight more to the opposite behaviour.

2.2. 24 hour and temperature

The 24 hour course in window use cannot be seen apart from the temperature dependency. Therefore we produced a more 3-dimensional graph with vertically the percentage of open windows, horizontally to the righthand 0 to 24 hours of all days and into the backplane the outside temperature from -7.5 degree C. in the front to 22.5 degree C. in the back (figure 2). In figure 2 all 16 windows are plotted separately. The position and numbers of the windows are given in figure 3. It has to be noticed that these figures are the mean values for all 80 apartments, so if one group opens some windows during the morning and another group opens similar windows successively in the afternoon, there may be a constant number of open windows during the day and no changes seem to occur round 12:00 while reading the figures.
All windows show a more or less steady level which is temperature dependent but constant in time. On that constant level a daily pattern is added. This daily change is small relative to the constant level. This means that a lot of windows are set open or closed and left in that position for more than one day. This is the case for most ventlights , a bit less for larger windows

and not for the balcony door. Moreover the daily changes seem to be more or less constant as a function of temperature. This is true for the bedroom windows, and a bit less for the kitchen windows but not for the balcony door. The day peak for most windows occurs round 9:00 but 18:00 for the kitchen and 17:00 on hot days for the front door.
After having seen the results it is quite easy to give some explanation for these temperature and 24 hour patterns.
Kitchen windows need to be used also in cold weather at specific times of the day round 12:00 and 18:00 . In bedrooms windows can be opened after people got up and left open for hours without causing comfort problems because no one is in there. So also on cold days these windows can be used to air the room. Ventlights can be left open (ajar) without also causing draughts on cold days. Therefore there is little need for often changing positions of these windows .

2.3. Hierarchy

With hierarchy here we mean the rank of windows with respect to the number of hours a day they are open . Balcony side windows are opened more than gallery-side windows. The most frequently used windows are in the bedrooms. Ventlights are used more than casement windows. The front door is open for the shortest time followed by the casement window in the living room. Instead of opening the casement window people open the balcony door here.

2.4. Instruction

For some inhabitants the instruction would cause more use of windows, for others it meant less use of windows. We calculated the total effect of the instruction just by splitting up the window use as a function of temperature in a part before the instruction and a part after. For all 16 windows these graphs are given in figure 4. As can be seen there is a small total effect for some windows. For instance the kitchen casement window is used more often after the instruction, the windows in the livingroom show a more frequent use but in the bedrooms there is no clear decrease in large open windows. A lot of windows are opened more at low temperature and less at high temperature, so they give a more constant level less dependent on the temperature (this is not understood). When we look at these figures for all 80 apartments it can be said that no major energy saving can be expected from this instruction. But we must be careful as here we did not measure the difference between a wide open window and one set ajar. As changes in hours open are so small the total effect, saving or loss, will be dependent on how wide windows have been opened.

We have also looked preliminarily at the behaviour of individual inhabitants. This is shown in figure 5 which needs an explanation. On the left side above each other the 16 windows of one apartment are plotted against 24 hours of the day. Per window two "bar"graphs are produced one full= before and one dashed = after instruction indicating that a window has been open or not. The "bars" are vertically and 10 minutes wide but only the envelope has been plotted. Here four similar days (same meteo) are selected before the instruction and four comparable days after . If a window has been open on a time interval on all four days the little "bar"graph for that window fills the assigned rectangle. If it is filled for 3/4 it means that on three of the four days the window has been open on that moment out of the 24 hours, and so on.

So in this part the moments and number of days a window has been open can be seen.

On the righthand side the total duration of open window in hours per day is labelled and also indicated with a horizontal bar. This is also done before and after the instruction. This part gives a faster indication whether a window has been opened more or less hours per day.

On the bottom the total number of "hours open window" is summed for the 16 windows, again before and after the instruction.

Up till now only a small number of these plots has been produced. It appeared that there are inhabitants that follow the window behaviour example incredibly well. But others did not change at all or opened more windows after the instruction. It is impossible to investigate the changes in behaviour by comparing these kindsof graphs for all 80 apartments on a variety of meteorological conditions. The way in which we planned to do this is to make a model of the behaviour for every apartment and window before and after the instruction and then compare either the difference in the "model before" and the actual measured "behaviour after" or the difference between the "model before" and the "model after". This can be done by means of hours per day difference as a function of time, temperature and so on.

3. Conclusion

A large amount of data has been gathered, from which a lot of information can be obtained, but only about this (special) apartment building and the Dutch climate. There is a good view on the number of open windows as a function of

the 24 hours of the day and as a function of outside temperature.
The instruction has been followed by some inhabitants,others did not change their behaviour (modeltechniques have to give the final answers).
The hierarchy shows a preference for the use of balconyside bedroom windows.

4. Literature

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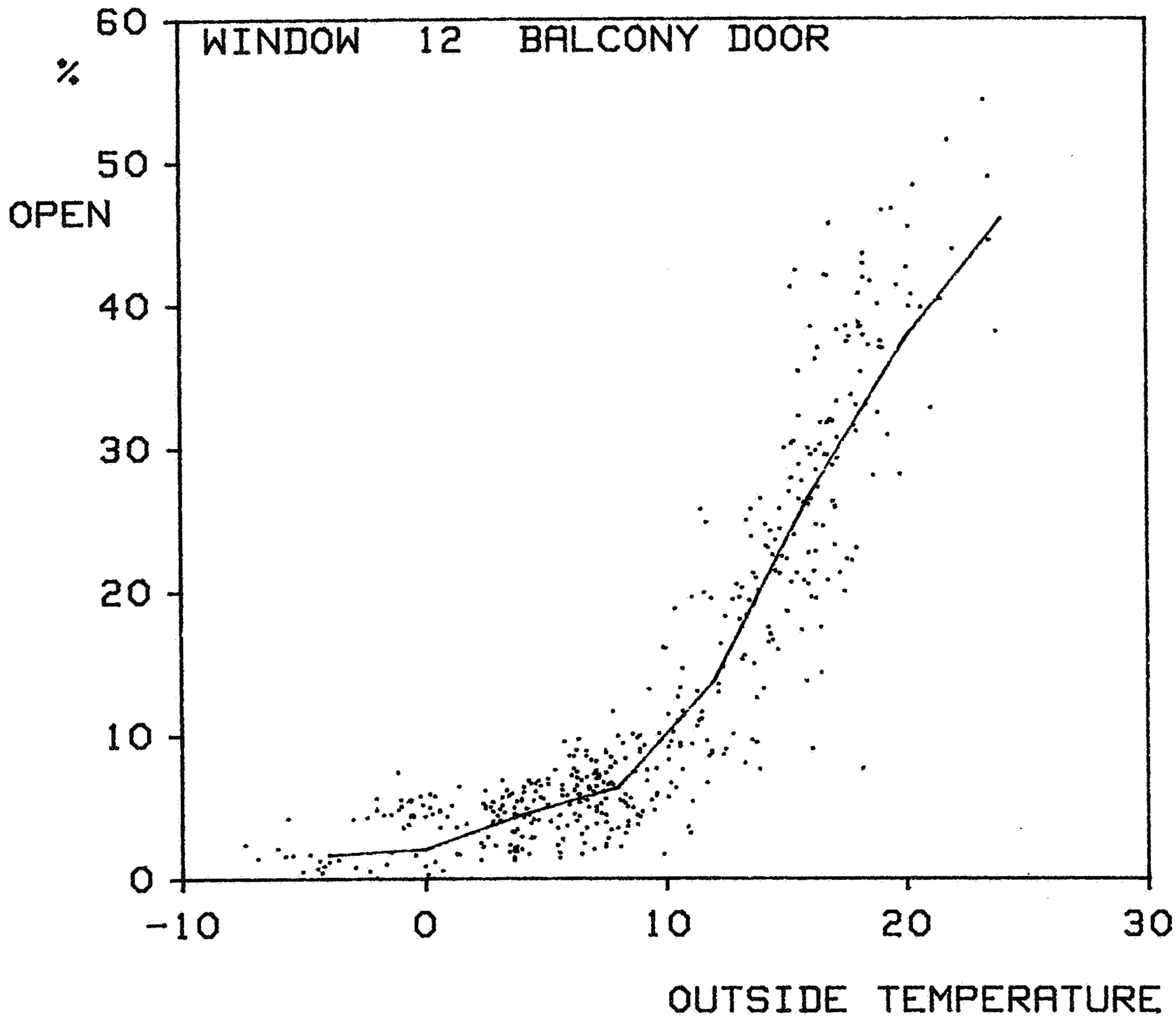

FIGURE 1: Use of the balcony door as a function of the outside temperature. Every dot is a daily mean value.

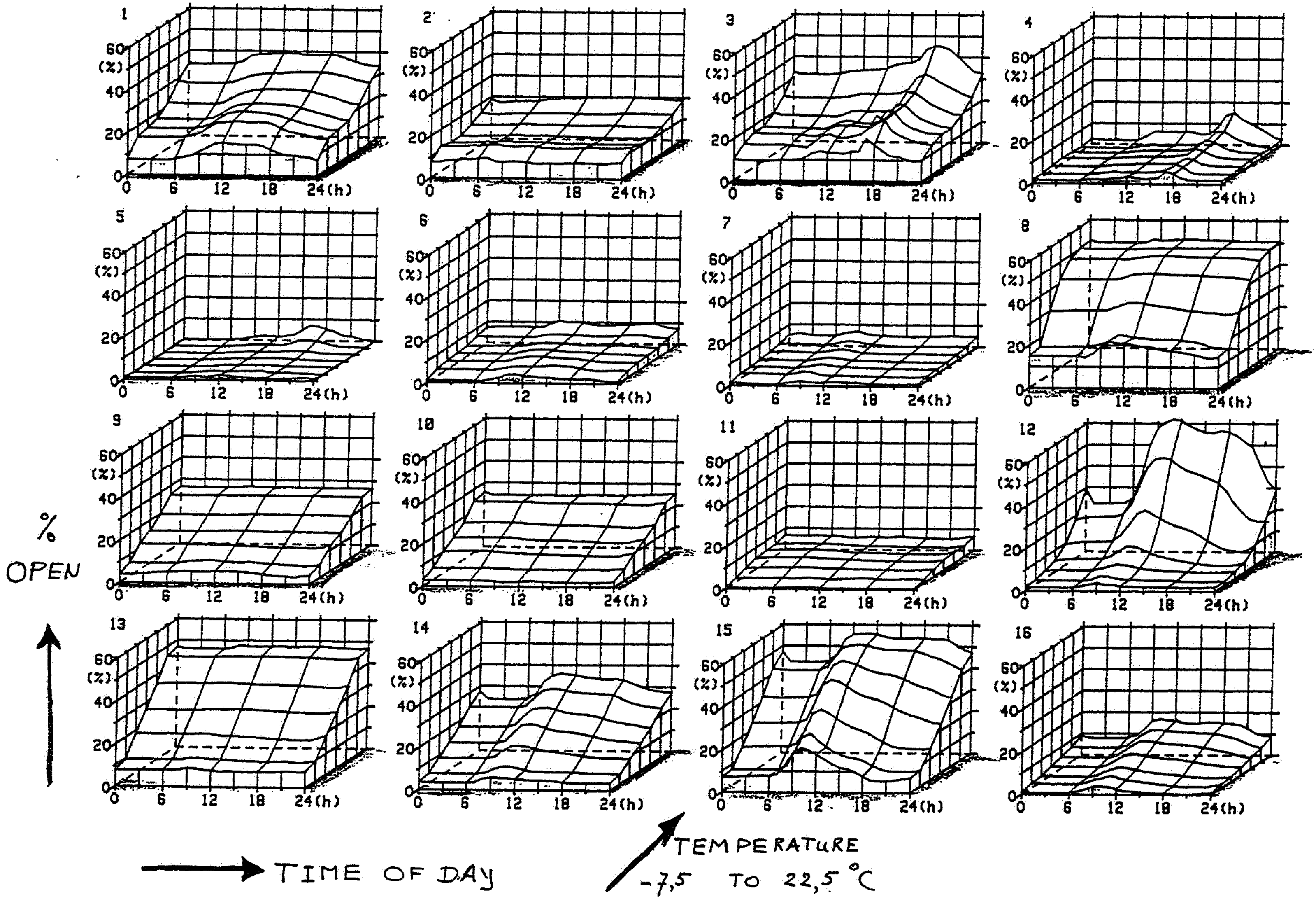

FIGURE 2: Use of the 16 windows as a function of temperature and 24 hours of the day.

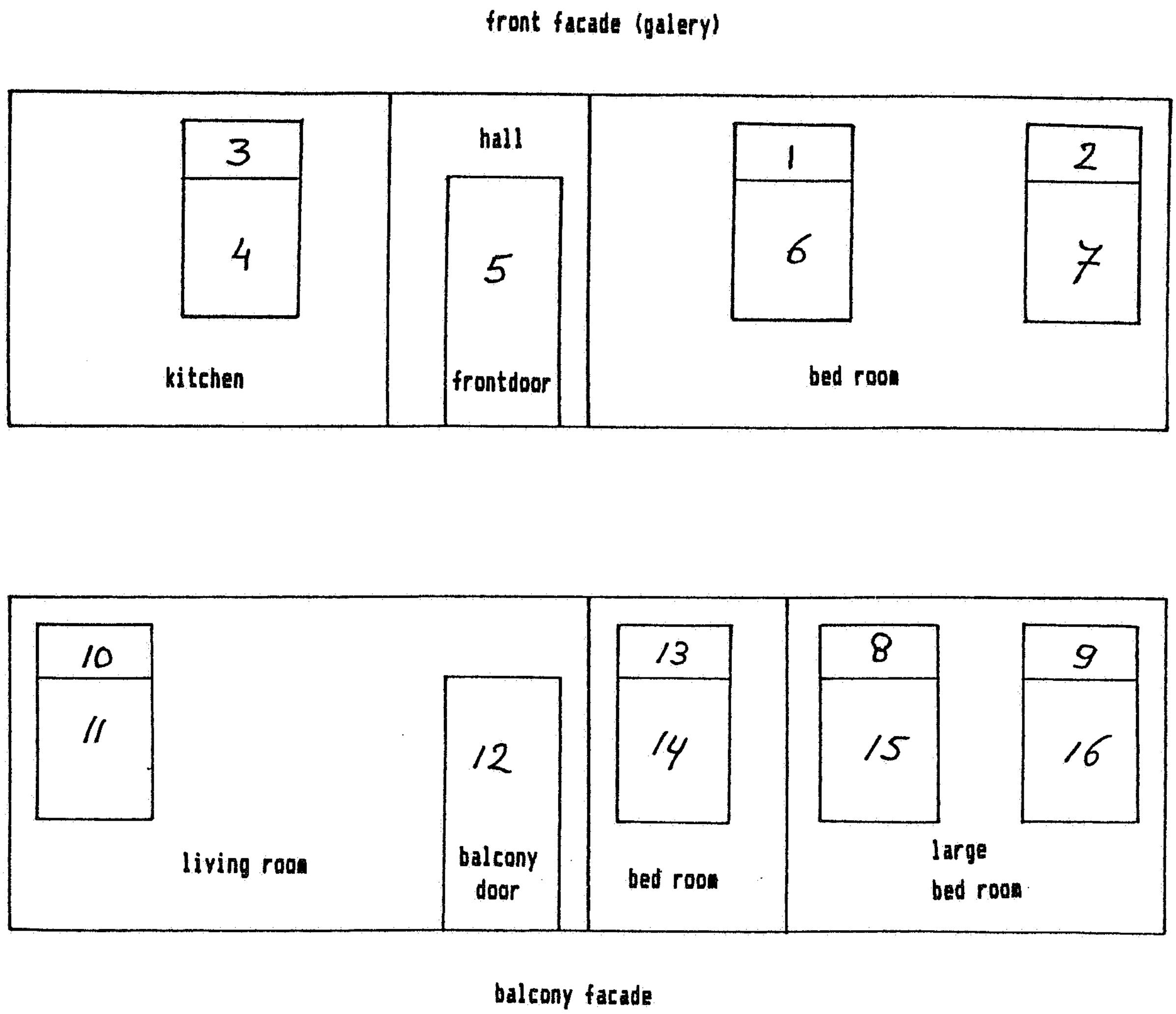

FIGURE 3: Numbers of the windows on the front (gallery) and rear facade (balcony).

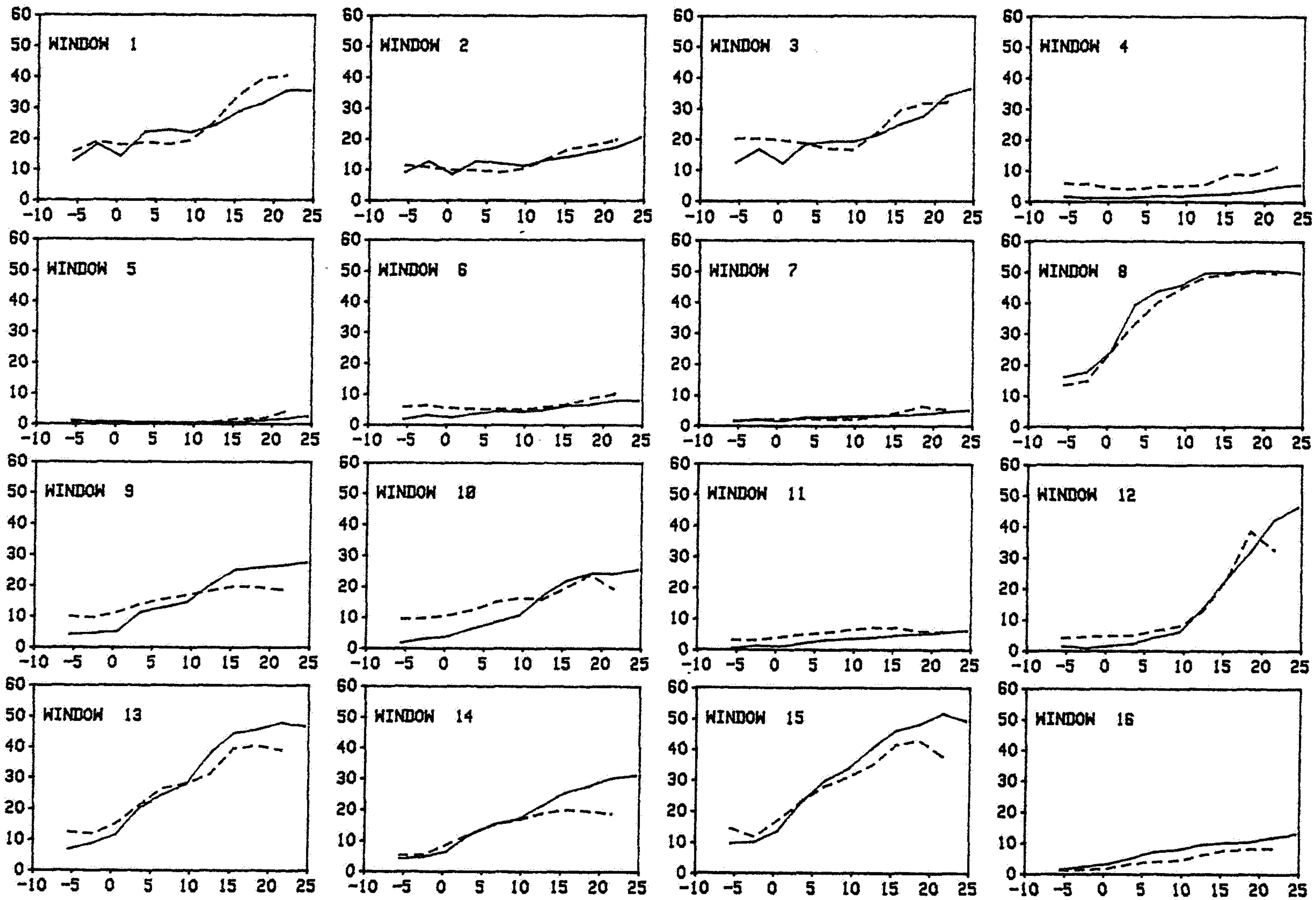

FIGURE 4: 16 windows before and after the instruction as a function of temperature.

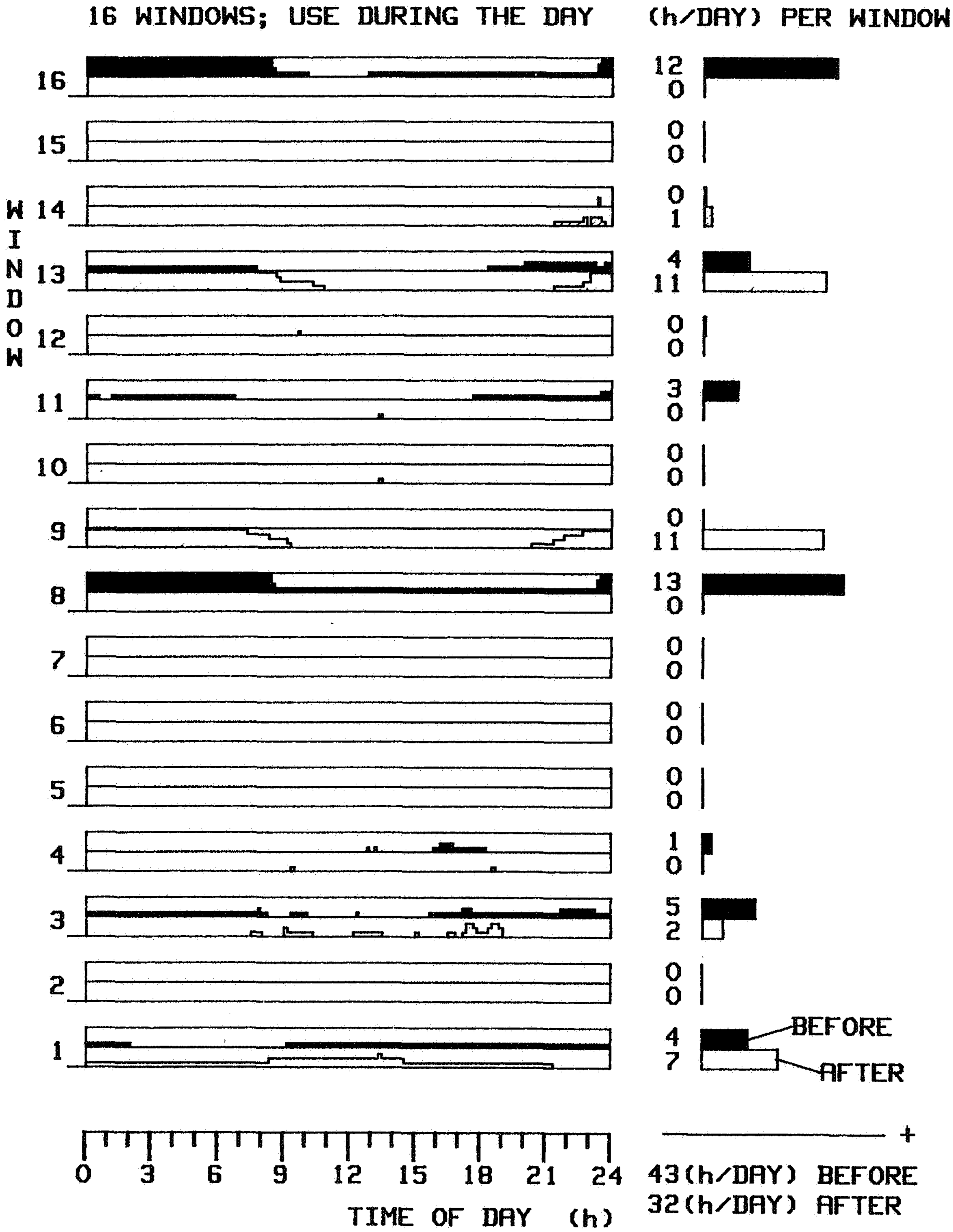

FIGURE 5: Comparison of the use of windows on four comparable days before and four days after the instruction. Only for one apartment.

OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER S.5

INHABITANTS' BEHAVIOUR WITH RESPECT TO VENTILATION

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Synopsis

During winter periods in four types of newly built terraced dwellings and in apartments of a flatbuilding, the daily behaviour and motivations of the inhabitants with respect to airing and ventilation have been studied. In total the information was obtained from 279 households. A combination of verbal interviews, diaries and technical measurements are used as methods of investigation.
On basis of the findings, calculations can be made about air flows in occupied dwellings. The results of these calculations can be related to indoor climate problems with smoke, smell, damp, air flows and temperature. A large number of factors are found which determine the behaviour. Because most of the behavioural factors can hardly be influenced, it is recommended to look for better technological solutions.
Since it appeared that most problems of indoor climate are not caused by deviant patterns of behaviour, these technological solutions ought to be adapted to the standard behaviour patterns and wishes of the inhabitants.

Introduction

In order to assess the functioning in practice of several newly developed heating systems and/or building constructions to save energy, the daily behaviour and the opinions of the inhabitants of four types of terraced dwellings have been investigated during winter periods. One of the aspects which was studied was the behaviour with respect to airing and ventilation and the motivations which play a role to it.

The four types of these one family houses were situated in the locations Almere (44 dwellings), Oosterhout (36 dwellings), Zwolle (99 dwellings) and Huizen (31 dwellings).

As well as these studies in newly built terraced dwellings, a very comprehensive investigation has been performed in an apartment building in the city of Schiedam. The main purpose of this project was the assessment of the inhabitants' behaviour and motives with respect to ventilation and its relation to inner and outer climatic conditions.
Other purposes were a study of changes in behaviour as a result of information and instruction to the inhabitants and to make an estimation of the energy loss resulting from this behaviour.
The investigation concerned a total of 70 identical apartments and was performed from November 1984 to April 1986.

The above-mentioned projects were and are carried out by the Netherlands Institute of Preventive Health Care-TNO (NIPG-TNO), in close co-operation with the TNO Division of Technology for Society (MT-TNO), Department of Indoor Environment.
Some results which will be presented in this paper were already published in (1,2,3,4,5).

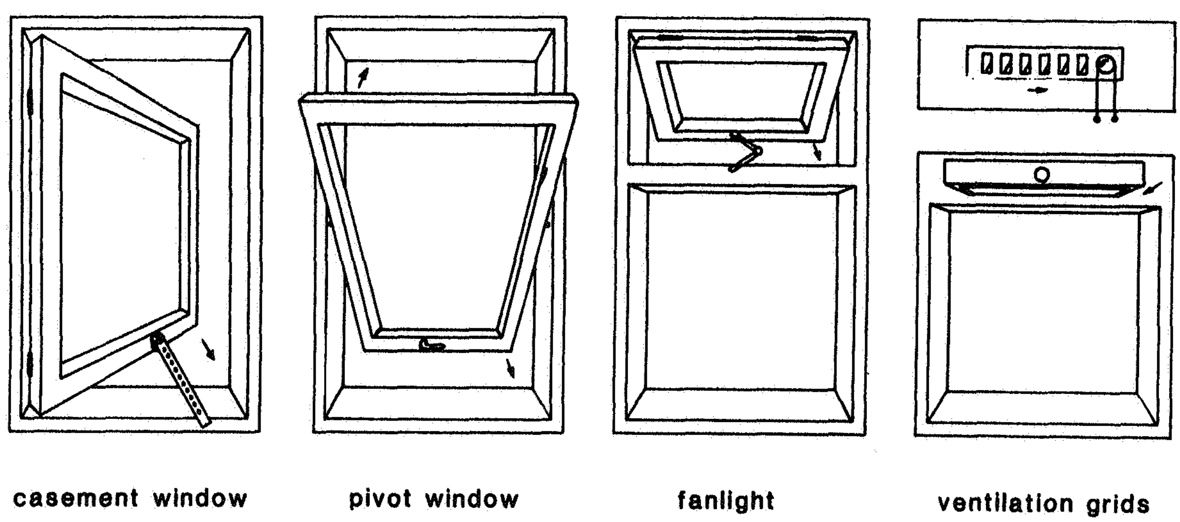
Methods of investigation

The information of the behaviour and opinion of the inhabitants has been obtained by extensive verbal interviews. In addition, in three of the five projects (Oosterhout, Huizen and Schiedam), the respondents were asked to fill in a prestructured 'diary' (logbook) during periods of one or two weeks. The diaries concern per hour information about presence at home, and the use of windows, ventilation provisions, doors inside, and heating systems. In Oosterhout and Huizen, the mean outside temperature was about +3°C during the daytime in the diary period.
In the project Schiedam the diaries are used in similar apartments during three periods, namely in winter 1985 (at 3°C), summer 1985 (at 18°C) and winter 1986 (at -2°C). Moreover, during the one-and-a-half-year period of investigation, the state of 1280 windows being open or closed has been continuously registered in a computer by means of the use of reed relays and magnets fixed to the window-frames.

Characteristics of the dwellings

As stated above the investigation was made in four types of newly built terraced houses and in apartments of a nearly 20 year old flat-building. In table 1 some characteristics of the dwellings are given. Except for the project in Huizen all houses are rented and were built under the conditions of social housing programmes. In Huizen the electricity used to heat is produced by two windmills. Some of the dwellings in Huizen also have a facade to a common arcade.
In Almere and Zwolle a part of the dwellings are provided with a warm air heating system, a system which requires a mechanical balanced ventilation and restricted airing behaviour by the occupants themselves.
If mechanical ventilation is installed, in principle the 'slow speed' state of the ventilator is usually adjusted to an air flow of about 150 m³ per hour. In air heated dwellings a warm air flow can be increased to 225 m³ per hour.
Four types of windows or ventilation provisions can be distinguished: casement windows (in the Netherlands usually hinging to the outside), pivot windows (with a horizontal axel in the middle), fanlights and ventilation grids (see figure 1).

Figure 1. Types of windows or ventilation provisions



Although in Oosterhout, in Schiedam and partly in Zwolle and Huizen the dwellings were designed with a 'closed' kitchen, only in Oosterhout a moderate part of these kitchens (36%) were really kept closed by a door.

In a small number of dwellings measurements were taken of their airtightness. In the dwellings in Oosterhout the mean airtightness is worst. It appeared that the variance in airtightness between identical dwellings can be considerable.

With all ventilation provisions and windows closed, the air leakage of Dutch terraced dwellings varies from about 130 m^3 per hour in "airtight" dwellings to circa 325 m^3 per hour in "normal" terraced dwellings (at a windspeed of 5 m/s and Δt (inside-outside temp.) of 13°C) (6). The airtightness of flatbuildings varies between 45 to 130 m^3 per hour respectively. The dwellings of the projects here concerned tend to be fairly "airtight".

Table 1. Characteristics of the dwellings per location

	Volume	n bedrooms	mech. vent.	'open' kitch.	type of windows	airtightness (q_{50} m^3/s)	number of dwellings
Almere (rad)	300	4	yes	yes	C,F,G	0,41	31
Almere (air)	300	4	yes	yes	C,F,G	0,41	12
Oosterhout (rad)	275	3	no	no	C,P,G	0,90	36
Zwolle (rad)	225	2	yes	80% y	P,G,C	0,25	31
Zwolle (air)	225	2	yes	60% y	P,C	0,25	68
Huizen (arc,coll)	300	4	yes	yes	P,G	0,24	9
Huizen (coll)	300	3	yes	77% y	P,G,C	0,35	22
Schiedam(flat,coll)	250	3	no	no	C,F	0,27	70

rad = radiator heated
air = warm air heated
arc = front to an arcade
flat = apartment in flatbuilding
coll = collective radiator heating

C = casement window
P = pivot window
F = fanlight
G = ventilations grids

Characteristics of the occupants

Those adults were selected as respondents, who usually are at home mostly (predominantly women). Assistance by other occupants in answering the questions was allowed.

In table 2 a number of socio-demographic and other characteristics of the occupants are given per project.

Table 2. Characteristics of the occupants per location

	n occupants (mean)	% > 28h/w nobody at home	% ≧1 occupant ≧ 50 year	% smoking 5 cigarettes	% thin clothing prefered	number of dwellings
Almere (rad)	2,9	10	10	61	29	31
Almere (air)	3,2	17	8	50	30	12
Oosterhout (rad)	2,9	31	17	42	35	36
Zwolle (rad)	1,8	61	6	61	26	31
Zwolle (air)	1,8	50	7	46	22	68
Huizen (arc)	2,7	33	0	44	0	9
Huizen	3,0	36	0	55	0	22
Schiedam	2,6	14	46	47	30	70

From these characteristics the main difference between the projects is that the number of older occupants is relatively high in Schiedam. In Zwolle the households are smaller (35% consist of one person) and the occupants spend less time at home than in the other locations.
Where it is asked it also appeared that the washing machine is used about 1.5 times the number of occupants per dwelling and that on an average the shower is used circa 8 minutes per day per person.
From the verbal interviews some characteristics are known about the state of the 'indoor climate' in the distinguished projects. (table 3)

It appeared that the mean value of preferred inside temperature of the livingroom is 20,4° C and that only a restricted number of respondents (about 15%) prefer a warm (≧ 18° C) bedroom.

Table 3. Indoor climate per type of dwelling.

	LIVINGROOM temperature ° C		LIVINGROOM % problems with					% prefered BED ROOM temp. > 17°C	N
	prefered	measured	too cold	condensation	draught	cig.-* smoke	cooking smell		
Almere (rad)	20,1	20,7	6	26	42	42	52	19	31
Almere (air)	20,6	19,7	25	33	67	100	67	33	12
Oosterhout	19,5	~19 (17,5/24h)	25	19	83	47	3	11	36
Zwolle (rad)	20,2	19,2**	25	13	68	9	35	10	31
Zwolle (air)	20,5	20,6**	21	6	12	16	28	12	68
Huizen (arc)	20,9	21,1	22	0	11	50	44	44	9
Huizen	20,3	20,3	27	9	36	8	33	27	22
Schiedam	21,0	20,1**	11	31	50	24	9	7	70
weighted mean values	20,4	20,1						14	279

* If ≧ 5 cigarettes smoked per day.
** Measured at a maximum outside temperature of ≦-5° C

Table 3 also shows problems with condensation draught, cooking smells and cigarette smoke that are in a substantial number of the dwellings. In nearly all projects the heating of the dwelling gave reasons for dissatisfaction too. Especially in Zwolle and Huizen technical problems arose with the heating system, while in air heated dwellings the (cold) air flows often caused complaints.

It is important to emphasize that problems with draught are not necessarily related to airtightness of dwellings. In airtight dwellings draught often is caused by relatively small "leaks" like ventilation grids (in Zwolle) or key-holes and letter-boxes (in Almere).

Results

In the projects mentioned above the occupants were questioned about how they ventilate and air their dwellings.
To ventilate is defined as to provide continuously a certain rate of refreshment of the indoor air by means of the use of ventilation grids, fanlights, leaving a window ajar or the inside door(s) of the living-room opened.
It is calculated that at a windspeed of 5 m/s and a temperature difference of 15 degrees the ventilating air flow will vary between 2-10 m^3 per hour (grids) to 50 m^3 per hour (fanlights) approximately (7). An open door inside the dwelling will generate air flows of approximately 300 m^3/h if the temperature difference between the hall is 1 degree to 600 m^3/h if this difference is 4°.

Airing is the opening of windows more than ajar during a certain period. This results in an air flow between 36 - 360 m^3 per hour depending on the width of opening.

The living-room

In table 4 the mean number of hours per day is shown in which the occupants in the different projects usually ventilate and air their living-room in an average winter period, with normal Dutch climatological conditions.

On the basis of the assumed air flows given in table 4, a rough estimation can be made about mean air exchange in the living-rooms of the distinguished projects. In these flows the rate of airtightness of the construction of the dwellings (see table 1) is not included.

The Dutch ventilation standard is based on an air exchange of 25 m^3 per hour (or 7 dm^3 per second) per person.

It will be clear that the presence of mechanical ventilation highly influencesthe existing air flow in the livingrooms.

Table 4. Airing and ventilating in the livingrooms

proj. nr.	location	hours per day: outward airing	hours per day: outward ventil.	hours per day: mech. ventil.	hours per day: inward (door)	estimated mean air flow in m^3 per hour: from outside	estimated mean air flow in m^3 per hour: from inside by door
1a	Almere (rad)	0,7	4,0	24	6,4	88	80
1b	Almere (air)	0,8	2,9	24	0,5	182***	10
2	Oosterhout	0,5	7,1*	0	4	7	83
3a	Zwolle (rad)	0,8	24,4*	24	3,2	92	40
3b	Zwolle (air)	0,0	0,5**	24	4,5	171***	56
4a	Huizen (arc)	0,4	55*	24	3,2	83	40
4b	Huizen	0,3	27*	24	7,5	80	94
5	Schiedam (W'85)	0,7	1,5	0	17,5	8,3	219
assumed air flows in m^3/h (per proj.nr.)		200	2(4a,b) 10(2,3a) 40 (1a,b,3b, 5)	75 (1a,3a, 4a,b) 170*** (1b,3b)	300 500 (1b,2)		

* Sumtotal of the use of more than one ventilation grid.
** No ventilation grids present
*** Partly recirculation of air

The mean total air exchange is lowest in the dwellings in Oosterhout. It is the very project where a substantially higher number of the respondents mention problems with the supply of fresh air, namely 36%.

In its first column table 5 gives the percentages of livingrooms in which the ventilation provisions (except from the mechanical ventilation) never or seldom (less than one hour per day) are used during winter time.
In the second column the percentages of livingrooms are presented in which the airing is extensive (more than one hour per day, with an estimated air flow of ≥300 m^3 per hour or ≥ 84 dm^3 per second). In most cases the indoor air quality was mentioned as a reason for extensive airing.

Table 5 Minimal and maximal use of the provisions in the livingroom.

	N	minimal use		extensive use	
	total	%	(N)	%	(N)
Almere (rad)	31	29	(9)	23	(7)
Almere (air)	12	25	(3)	17	(2)
Oosterhout	36	31	(11)	3	(1)
Zwolle (rad)	31	13	(4)	6	(2)
Zwolle (air)	68	96	(65)*	0	(0)
Huizen (arc)	9	11	(1)	0	(0)
Huizen	22	27	(6)	0	(0)
Schiedam	70	36	(25)	11	(8)

* no ventilation grids installed.

In Oosterhout and Schiedam, where the indoor air quality is most critical in theory, because of the lack of mechanical ventilation, a high proportion of the 'non-ventilators' have usually opened the inside door during a long time. In Schiedam this is the case with 24 of the 25 dwellings; in Oosterhout in 8 of the 11 dwellings.

The bedrooms

The time windows are opened in the bedrooms is dependent on the use of these rooms. The approximate relation between the main (parents') bedroom, the bedrooms of the children and bedrooms not used to sleep is 6:3:2.
It is found that on average at 'normal' winter conditions in approximately 60% of the bedrooms of the parents a window is opened during the night. Even on extremely cold nights (-8° C) a window or fanlight is opened in 12% of the main bedrooms.

The mean time per day in which the windows in the bedrooms used to sleep are opened in the different projects is given in table 6. From information about how wide the windows were opened and the type of windows a rough estimation has been made about the percentage bedrooms in which the air flow is more than 125 m³ per hour.

Table 6. Use of the windows in bedrooms

	hours per day	% air flow > 125 m³/h	total number of bedrooms
Almere (rad)	5,8	59	95
Almere (air)	1,4	36	25
Oosterhout	6	53	70
Zwolle (rad)	6,9	5	39
Zwolle (air)	5	20	76
Huizen	3,4	8	39
Schiedam (w. '85)	4,3 + 9,8*	75	123

* windows = 4,3 hours
fanlights= 9,8 hours

The length of time the bedroom windows are opened is also related to the functioning of the heating system, which resulted in too warm bedrooms in Oosterhout and Schiedam and too cold bedrooms in Huizen en Zwolle*.

* In (8) it is calculated that in the case of Oosterhout, where the ducts of the radiator heating system horizontally run through a bedroom, a window must be opened 6 hours to cool the bedroom from 18° C to 15° C at an outside temperature of 5° C.

The kitchen

As already indicated in table 1, in the dwellings in Oosterhout and Schiedam mechanical ventilation is lacking. (In 21 kitchens in Oosterhout and 17 kitchens in Schiedam the occupants used a ventilationhood, but these did not significantly lead to a better judgement about the indoor air quality). Moreover in these projects the kitchens are not designed as a part of the living-room although the door from these kitchens to the hall of the dwellings predominantly is opened: in 64% of the cases in Oosterhout and 93% of the cases in Schiedam. In Schiedam a gas geiser to produce hot water was installed in the kitchen. On average, airing took place 45 minutes per day in Oosterhout (by means of a door to the garden) and about 20 minutes in Schiedam (by means of a casement window). Moreover in Schiedam a fanlight was opened 3 hours per day. In Oosterhout a small ventilation grid had been installed. On average this was opened 6,7 hours per day.
Assuming the way of airing and use of the kitchen, an estimation can be made that the mean air flow directly from outside is less than 25 m^3/h per day in about 50% of the kitchens in Schiedam.
With respect to dwellings with an "open" kitchen as part of the living-room, it is already stated (table 3) that in spite of mechanical ventilation provisions, in a high percentage of these dwellings problems exist with cooking smells.

Motives to air or ventilate

In answer to the "open" questions why people ventilate or air as they do, a need for fresh air is mostly mentioned. Especially the bedrooms are preferred to be "fresh". (What is meant by "fresh" probably is a combination of temperature, smell and amount of dust).

Other spontaneous mentioned reasons to ventilate or air are to get rid of cigarette smoke and, depending on the project, vapour and condensation problems and cooking smells. Household activities like vacuum cleaning and "airing" blankets are mentioned as reasons too.

In table 3 information has already been given about the problems with indoor climate factors and the (low) percentage of dwellings where a "warm" bedroom is preferred. (It's notable that a high proportion of respondents could not give a preferred bedroom temperature, but answered "fresh" only).

Especially in Almere the respondents complained about condensation on the (single glazed) bedroom windows and a way to get rid of it was to keep the windows opened. The condensation was partly caused by dampness from the bathroom, which was situated in the middle of the dwelling. The same type of location of the bathroom also plays a role where there are problems with condensation in Schiedam.

A part of the spontaneous answers given on the question why airing or ventilating or the method used referred to comfort and convenience. A door to a balcony or garden is preferred to a window.

Few respondents referred to the dense insulation of their dwellings.

The main reasons not to ventilate or air are sufficient indoor climate, air quality and draught. (Table 3 showed that in nearly all projects, including the most insulated dwellings, a high percentage of the occupants experience problems with draught). Especially the air flow through ventilation grids seems to produce annoyance. As reason not to air, the presence of plants, domestic animals and small children ought not to be neglected. Plants must be kept free from lice; canaries or parrots free from cold. The territory of children, cats, dogs and hamsters needs to be controlled. It appeared that the use of doors inside the dwelling is highly determined by them, together with arguments like habit and convenience.

Where mechanical ventilation is installed (in "open" kitchens),

sometimes complaints are expressed about noise annoyance. In another study (9) it is found that an emmission level of noise from a ventilator of 30 dB(A)L_{eq} in a living room, generates annoyance in 25% of the households.
In 5 of the 36 dwellings in Oosterhout traffic noise influenced the use of the windows in the bedrooms at night (in the other locations the outside noise levels were too low to influence the behaviour).
Finally, only a few respondents explicitly pointed out burglary as a factor to close windows.

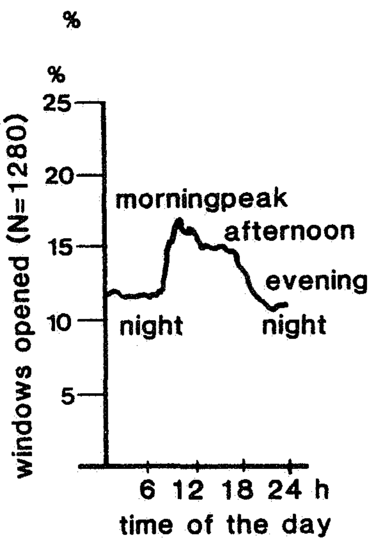
Correlated factors

The type of windows and the handiness to use and to wedge them influence the behaviour. Pivot windows tend to be less wide opened. From the Oosterhout project it is known that the use of casement windows is influenced by the direction of the wind, resulting in one hour difference in use on average per day. The same tendency is found in Schiedam.

Apart from architectural characteristics of the dwellings and applied technical provision, a number of behaviouristic aspects of the occupants can be correlated with the length of time in which airing and ventilating take place.
A comparison between dwellings in which the occupants were not at home less than one hour per day on average, with dwellings in which nobody was at home more than four hours per day indicated that, taking all provisions together, no clear difference is found in the mean time the windows were used per day. Only the (bedroom) windows were less wide opened. However, on the basis of the information from the diaries it was clearly found that in the periods of the day nobody was at home and if the windows are not easy to open from the outside, they were kept opened much shorter than on average: for instance in Schiedam in winter 1985: 0,3 hours against 2,3 hours per day (in half of the addresses all windows and fanlights were always closed when nobody was at home).

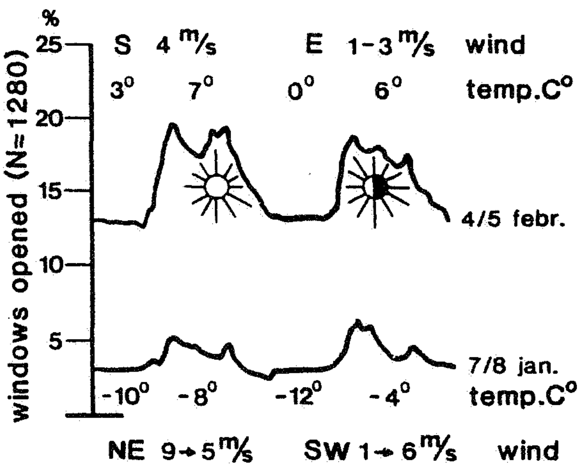
Per household the daily pattern in using the ventilation provisions and windows appears to be very consistent. In figure 2 this daily pattern is shown. At roughly the same climatical circumstances the variance in behaviour is low in the same households. "Deviating" behaviour has been found in the weekends.
Although seldom spontaneously mentioned by the occupants (it's taken for granted), a strong correlation has been found between the use of windows and outside climatical conditions like temperature, windspeed, wind direction and sunshine (1).
In this paper we restrict ourselves to the presentation of a figure which shows the percentages of windows opened in the flatbuilding in Schiedam during different circumstances. (figure 3).

Figure 2. Daily pattern of airing and ventilating



	weather night	weather day
temperature °C	8	9
windspeed m/s	7	8
winddirection	SW	SW/W
sun %		50

Figure 3. **Use of windows at different weathertypes**



Where occupants do smoke, the ventilation provisions in the living-room are used about twice as long as those where occupants do not smoke. On the basis of the information from the diaries, smokers to non-smokers ratio's are found of 1,9 in Schiedam, 2,0 in Oosterhout and 1,6 in Huizen. The results from the interviews in Almere (rad) even showed a ratio of 3,2, but in Zwolle (rad) no clear difference was found.
With respect to problems with condensation it appeared that its relation with the use of the ventilation provisions is subject to two interpretations: condensation owing to too short ventilation at too low temperatures inside; or the condensation problems themselves are solved by longer ventilation, but create derived problems like draught, too low temperatures, or more use of heating energy.
For instance in the living-rooms in Schiedam with problems of condensation the occupants ventilate on average 1,6 hours per day versus 2.4 hours in livingrooms with no condensation.
On the contrary in Oosterhout the living-rooms with problems of condensation were ventilated longer: 4.3 versus 3.3 hours per day. In the living-rooms with condensation a mean inside temperature was measured of 16°C, against 18°C in rooms without condensation. In bedrooms without condensation problems in Oosterhout the (double glazed) window was opened 7.2 hours per day on average with a mean inside temperature of 18°C. However, in the bedrooms with condensation problems, the window was opened 2.7 hours per day at a mean inside temperature of 14.4°C.

Preferred clothing behaviour is related to a preferred inside temperature. It is found that light clothed people prefer a 2°C higher temperature on average in the living-room than people with heavier clothes.

In the tables 7 and 8 relations are shown which are based on information obtained from the verbal interviews taken in Huizen, Zwolle and Schiedam. Per project a simple Pearson correlation has been calculated between the variables stated and the rate of ventilating (in hours) and airing (in hours times width of opening of a window) per day per dwelling.

If the correlation is marked with ** it is judged as significant (p value is ≦ 05), if marked with * a tendency of a relation is assumed (.05 <p ≦ .10).

Table 7. Correlation between variables and ventilation and airing of the livingroom and/or kitchen.

	Huizen (n=31)		Zwolle (n=104)		Schiedam (liv) (n=70)		Schiedam (kitchen) (n=70)	
	low vent.	air	vent.	air	vent.	air	vent.	air
low energy consumption			**			*		
low number dwellers		**						
low age respondent	-*			**	*		-*	
low absence	*		-**					-*
low thermostat evening	**			-*	/	/	/	/
low thermostat 24 hours			-*				-*	
few hours therm. low at absence	*				/	/	/	/
few hours inside door liv.room open			-*		/	/	/	/
low temp. livingroom prefered	**						-**	
low temp. livingroom measured				-**				
low temp. bedrooms prefered								-**
low satisfaction indoor climate	**							
low minutes of shower-bath								
low freq. of use of washing-mach.		**					**	
many problems with:								
heating ground floor								
heating bedroom floor					/	/	/	/
cooking smells								
sigarette smoke			-*		*	-*		
fresh air						-*	*	
condensation								-*
draught	/	/						-**
cold radiation	/	/				-**		
cooling	/	/	/	/		-**		
low ventilating livingroom		-**		*				
low airing livingroom	-**		*					
low ventilating bedrooms			**	*	**		**	
low airing bedrooms		*	**	**	**			**

** p ≦ .05

* .05 < p ≦ .10

/ = not analysed

Table 8. Correlation between variables and ventilation and airing of the bedrooms.

	Huizen (n=31)		Zwolle (n=104)		Schiedam (n=70)	
low	vent.	air	vent.	air	vent.	air
low heating energy consumption						
low numer dwellers			-**			-*
low age respondent						**
low absence						-**
low thermostat evening		-*			/	/
low thermostat 24 hours		-*				
few hours therm.low at absence			**	**	/	/
few hours inside door liv.room open			-**	*	/	/
low temp. livingroom prefered	-*			-*		
low temp. livingroom measured			-**			
low temp. bedrooms prefered			-**	-**		
low satisfaction indoor climate			-**			
low minutes of shower-bath		**	-*	**	*	
low freq. of use of washing-mach.	*			*	**	
many problems with:						
heating ground floor		-*				
heating bedroom floor		**			/	/
cooking smells		*				
sigarette smoke						*
fresh air						
condensation			-*			
draught	/	/				
cold radiation	/	/				
cooling	/	/	/	/		
low ventilating livingroom			**	**	**	**
low airing livingroom		*	*	**		
low ventilating bedrooms		-*		**		**
low airing bedrooms	-*		**		**	

** $p \leqq .05$
* $.05 < p \leqq .10$
/ = not analysed

The above mentioned findings are confirmed by the statistical information presented in the tables 7 and 8, although not in all three distinguished locations. In addition it can be stated that if people tend to ventilate or air their living-room at a high level, they also tend to do the same in the bedrooms. Moreover, the frequency of use of a shower-bath or a washing machine appears to influence the use of windows.

The consumption of energy to heat is primarily related by the mean state of the thermostat in the living-room. In turn the thermostat is sensitive to air flows from outside coming through the ventilation provisions.

Surprising may be the finding that the way the bedrooms are aired or ventilated does not influence the energy consumption. (This was also found in the project Oosterhout). The reason may be the fact that the bedrooms are usually heated only shortly or never. (In Schiedam and Huizen a correlation of .37 and .40 respectively was found between the number of radiators which are used and the consumption of energy to heat. In Zwolle this relation is leaking).

Validity and reliability

To assess the validity of the information from the respondents the results from the diaries (in (half) hours per day) has been compared with the results from the technical measurements (magnets on the window-frames) during the diary period.
Figure 4 shows the facades of an apartment in the flat-building in Schiedam and gives the codification of the windows.
It appeared that the correlation between those measurements was very high: If the windows or fanlight were opened more than one hour per day on average, in winter 1985 a correlation on individual level (per apartment) was found of .90 per window or fanlight on average and .73 if these were opened less than one hour per day. In summer 1985 the rates of correlation were .95 and .53, in winter 1986 .80 and .57 respectively.
Although not as high as above mentioned correlations, the information from the verbal interviews (taken before the diary period of winter 1985) concerning previous subjectively experienced "cold" and "not so cold" winter periods, fairly agree with the findings from the diaries too, assuming that the period in which the diaries were filled in (3°C during day time) as been defined as cold. In table 9 the mean times are given during which window opening occurred in winter 1985 according to the interviews, diaries and technical measurements taken in identical households (n=52).

Figure 4. Façades and codification of windows and fanlights in Schiedam

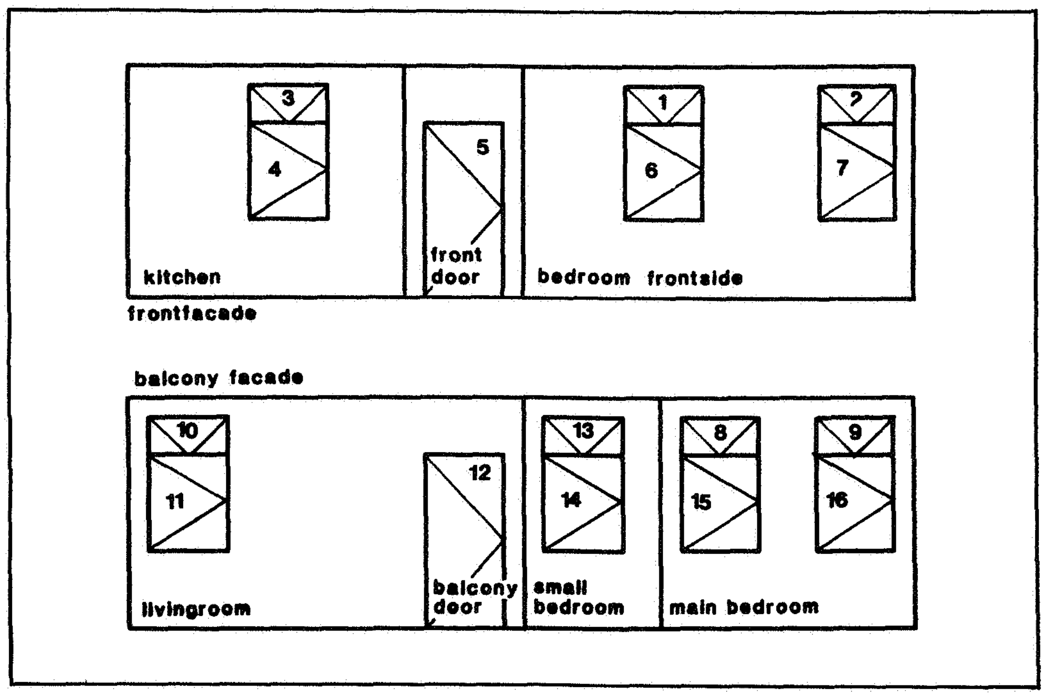


Table 9. Comparison between results from interviews, diaries and technical measurements

Codification (see figure 4)		Mean hours opened per day: interviews, less cold	interviews, cold	diaries	measure-ments
livingroom	10	3,9	1,5	1,1	1,5
	11	0,3	0,1	0,4	0,6
	12	2,4	0,9	0,7	0,8
small bedroom	13	11,6	4,4	5,1	5,5
	14	3,0	1,3	1,8	2,8
main bedroom	8	15,4	9,5	9,0	8,6
	9	4,2	1,9	3,6	3,4
	15	1,6	3,0	6,1	6,2
	16	5,6	1,3	1,6	1,6
bedroom front-side	1	5,9	2,6	4,3	4,5
	2	7,2	3,4	1,8	1,6
	6	0,6	0,3	0,9	0,6
	7	2,0	0,9	0,6	0,5
kitchen	3	5,7	3,4	3,0	3,1
	4	1,5	0,8	0,3	0,4
Total mean		4,7	2,4	2,7	2,8

In the 18 apartments where the occupants only participated in the interviews, they tended to be less at home or it concerned households with small children. However, no significant difference was found in the use of windows and fanlights between those who participated in the interviews (n=70) and those still participating during more than one year and three diary periods (n=38).

In theory a changed behaviour could also be caused by the magnets installed on the windows-frames and by the participation of the occupants at interviewing and diary keeping. However, apart from the already mentioned high validity of the results, a comparison shows no surprizing differences in behaviour with the results of diaries which are filled in by a reference group (occupants of apartments of another (identical) flatbuilding) during the same period in winter 1986 (see table 11). The main difference is the use of airing and ventilation provisions in the living-room, but this can be explained by the prevailing wind direction during the diary period (the livingroom of the main group was orientated to the east, those of the control group to the west).

Change in behaviour

One of the purposes of the investigation in Schiedam was to give information and instruction to the occupants how to ventilate and air sufficiently at minimal use of heating energy. The base of this information campaign was formed by the results of the interviews and the technical measurements of winter 1985.

Integrating behavioural aspects like smoking and the experience of aspects of indoor air climate, it was found that in about 10% of the apartments the ventilation tended to be too low, in another 10% clearly too high and in about 45% very unbalanced: too high in the bedrooms and too low in the living room or kitchen.
The information was given written and consisted in short of the following advice (table 10).

Table 10 Ventilation and airing advice

Bedrooms:		
daytime	:	casement window 20 minutes fanlight 1 cm wide continuously
nighttime	:	fanlight half opened continuously
Livingroom:		
If 2 persons present	:	fanlight half opened
If 4 persons present	:	fanlight opened totally or inside door opened, together with fan-light and windows opened in bedrooms or kitchen.
at night	:	after smooking a fanlight open
Kitchen:		
at cooking	:	casement window or fanlight open
after cooking	:	casement window 5 minutes fanlight few hours open

The written information was also sent by post to the inhabitants of other identical flatbuildings, but these inhabitants were not drawn into the investigations, except from a small number of them (n=27) used as a reference group.
On this basis of the diaries filled in in the same households (n=38), table 11 shows the difference in the total time the windows and fanlights were opened per day during the diary periods of winter 1985 and winter 1986. Also the time is given during which respondents in the reference group used their windows and fanlights in the same period in winter 1986.

Nearly all windows and fanlights were less opened in the winter period of 1986. Especially this is the case in the main bedroom, where both the casement windows and the fanlights were kept open half as long as in the winter period of 1985. With respect to the provisions in the living room it was found that especially those who prefer to wear light clothes ventilated or aired less: 3.3 hours per day in total in 1985 to 1.6 hours in 1986. The kitchen was ventilated or aired shorter by the lightly clothed respondents (3.1 hours in 1985 to 1.6 hours in 1986), but heavily clothed respondents ventilated or aired the kitchen longer on the contrary: 4.7 hours in 1985 to 5.5 hours in 1986.

Although the above mentioned results suggest an effect of the information campaign, this effect is highly influenced by climatical conditions: During the diary period of 1986 it was approximately 5°C colder on average, which will "automatically" lead to about 0.8 hours per day less use of provisions (1). Therefore it can be concluded that in total the information campaign only led to 0.6 hours per day less use of windows or fanlights per apartment.

Table 11 Comparison between 1985 and 1986.

Codification (see figure 4)		Mean hours opened per day main group 1985	main group 1986	reference group 1986
livingroom	10	1,1	0,7	1,9
	11	0,5	0,3	0,2
	12	0,7	0,4	0,7
small bedroom	13	6,5	1,9	3,6
	14	2,3	0,7	1,1
main bedroom	8	10,0	4,8	2,5
	9	3,6	1,9	3,1
	15	5,5	2,0	2,4
	16	1,6	0,4	2,2
bedroom front-side	1	4,7	3,3	4,8
	2	2,3	2,1	1,7
	6	0,4	0,6	0,3
	7	0,9	0,7	0,4
kitchen	3	3,8	4,3	3,9
	4	0,4	0,2	0,4
total mean hours		3,0 h	1,6 h	1,9 h
% windows opened		12,5 %	6,7 %	7,9 %

Conclusion

A large number of data are obtained to get insight into the behaviour and motives of occupants of dwellings with respect to ventilation and airing nowadays. Although only a part of these data are presented in this paper and more detailed information has not been analysed yet, it can be assumed that the results give a reasonably good representation of the "state of the ventilation art" in newly built dwellings in the Netherlands. The methods used, especially the combined application of verbal interviews, diaries and technical measurements, were successful. On the basis of the available information more precise calculations can be made about air quality and air flows in dwellings. It appeared that an air exchange which seems to be sufficient in a pure physical sense, does not exclude per definition problems of indoor air quality in practice.

Four types of factors can be distinguished which determine the experiences and the behaviour of the occcupants with respect to airing and ventilation:

- factors which cannot be influenced like personal characteristics of the occupants;
- factors which hardly or ought not to be influenced like the indoor climate preferred by the occupants and the indoor air quality they experience;
- factors which may be influenced, like specific routines in the daily household behaviour;
- and factors which can be changed in behalf of the occupants: characterictics of the dwellings and the applied heating systems and ventilation provisions.

Especially the last mentioned factors deserve the highest attention, in view of the reported deficiences in controling the indoor air quality and climate.

The results of the studies showed that most problems are not caused by "deviant" or "irrational" patterns of behaviour of the occupants. Therefore technological solutions ought to be adapted to these patterns not visa verse, as happens in more than one case, however well intended (reduction of costs, energy saving) that may be.

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OCCUPANT INTERACTION WITH VENTILATION SYSTEMS
7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER S.6

THE ROLE OF TRICKLE VENTILATORS IN DOMESTIC VENTILATION DESIGN

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SYNOPSIS

This paper discusses the use of trickle ventilators in the design for natural ventilation in dwellings. The discussion is based around the results of a field monitoring experiment where 17 out of 32 houses were fitted with trickle ventilators as a remedial measure to improve the distribution of ventilation and to reduce the occurrence of condensation. Reductions in condensation, effects on energy use, window opening and occupants views are considered. The paper concludes that trickle ventilators are a successful component part in the design of natural ventilation systems in dwellings.

1. INTRODUCTION

This paper discusses the use of trickle ventilators in the design for natural ventilation in dwellings.

Over the past decade in the U.K., in order conserve energy, the standard of domestic construction has become much 'tighter' in terms of reduced air infiltration. This has been achieved by the use of high performance components, better constructional detailing, and general draught sealing. It is now generally accepted that in modern 'low-energy' dwellings there is a need to design for ventilation to ensure occupants well being and to reduce condensation risks. Traditionally, in the U.K. domestic ventilation is predominantly natural, relying on air infiltrating through open areas (fortuitous and purpose made) in the fabric. Now the fortuitous openings are being reduced by tighter design and the traditional purpose made openings, ie. windows, are usually insensitive to the fine control needed for winter time ventilation.

Trickle ventilators are a component part of natural ventilation design in well sealed houses, offering an openable area sufficient for winter ventilation, that does not incur a significant energy penalty. There are three main designs for predominantly natural ventilation, involving the use of trickle ventilators, namely :

(i) Natural in/Natural out : using trickle ventilators as both the source of air inlet and outlet.

(ii) Natural in/Mechanical out : an extension of (i) with additional air outlet using mechanical extract.

(iii) Natural in/Natural out : using trickle ventilators as the source of air inlet with additional air outlet paths using stack ventilation ducts in the bathroom and kitchen (REF 1).

This paper discusses the first of the above schemes, which is currently the most common in operation in the U.K. The discussion is mainly based on the results of a monitoring experiment on a sample 32 houses of which 17 had trickle ventilators installed. Some initial results were presented in an earlier publication (REF 2) along with detailed ventilation measurements carried out on the houses. This paper presents a more detailed analysis of the trickle ventilators experiment, which was funded as a Department of Energy (BRECSU) Demonstration Project (REF's 3,4).

2. DESCRIPTION

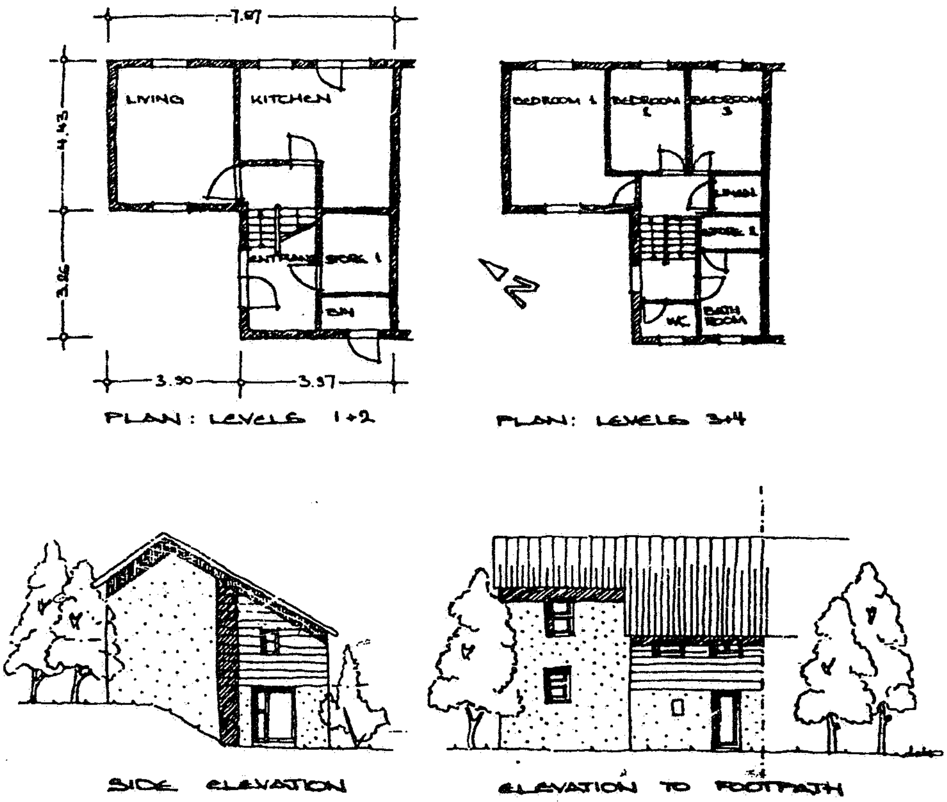


FIGURE 1. HOUSE PLANS AND ELEVATIONS

The houses were all three bedroom terraced houses (Fig 1), situated on a southwest facing hillside in Abertridwr, South Wales. Trickle ventilators were installed in the window frames of 17 houses out of the sample of 32 houses. The houses had previously been the subject of a 'better insulated houses' project (REF 5) and as such approximately half of the houses in each group (ie. those with and those without ventilators) had insulation standards in excess of what was then recommended by the UK Building Regulations. Holes were drilled in the window frames providing an open area of 350 sqmm (for a 'standard' ventilator) with the ventilator in the fully open position. Physical and social monitoring was carried out over approximately a 20 month period, beginning 6 months prior to the installation of the ventilators. The physical monitoring included the continuous measurement of energy use, internal air temperatures and external conditions, (REF 3) as well as ventilation and air leakage experiments (REF 2). The social monitoring included surveys of condensation occurrence, window opening, and occupants use and reaction.

Prior to the installation of the trickle ventilators, ventilation measurements carried out on the Abertridwr site showed that, although the whole house average air infiltration rates were reasonably satisfactory at 0.5 ac/hour, the individual room rates were in many cases extremely low and there were a number of serious cases of condensation and mould growth. Preliminary measurements in two houses which had trickle vents installed showed an improvement to the distribution of ventilation in the rooms together with a marked reduction in condensation mould growth (REF 3).

3. RESULTS

3.1 Reduced Condensation

For the occupants condensation becomes a problem when it manifests itself in mould or damp patches. It was therefore these visible signs that were considered when assessing the problem of condensation. The seriousness of mould growth was assessed according to its extent, being categorized as non-existent (none), present in the window recess (some), or present underneath windows and in other areas (severe). Three surveys were carried out, in the April 81, prior to the installation (the following January), in April 82 and in April 83. The results of the surveys are summarised in Table 1.

TABLE 1. CHANGES IN OCCURRENCE OF MOULD GROWTH

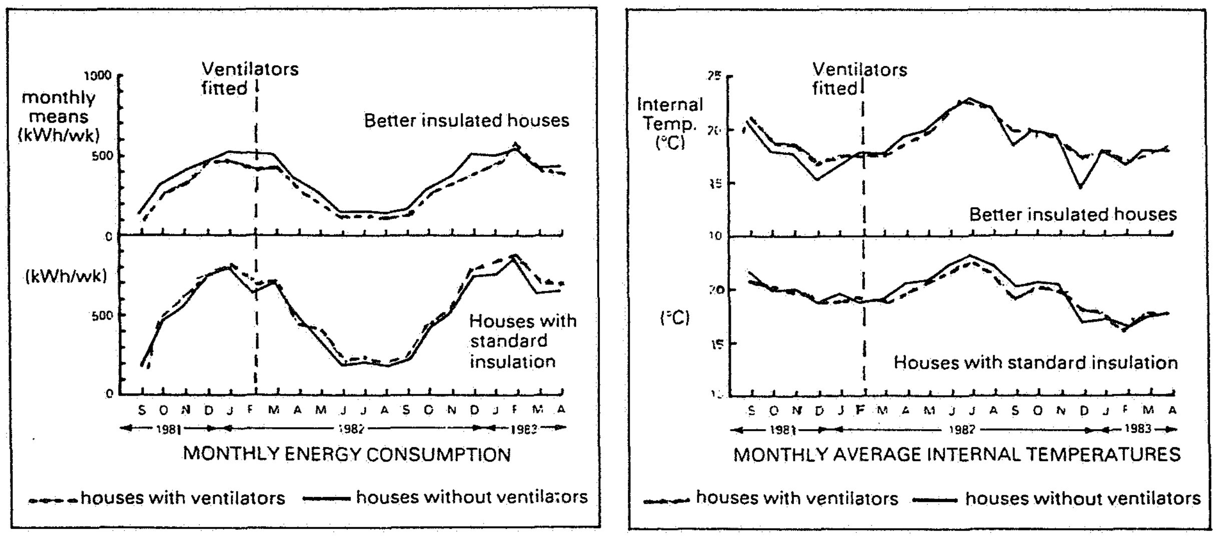
	Houses with ventilators (17)			Houses without ventilators (15)		
	severe	some	none	severe	some	none
Before April 82	6	2	9	/	7	8
April 82	2	6	9	2	8	5
April 82	1	7	9	4	7	4

Between April 81 and April 82, four houses with ventilators showed an improvement in the reduction of mould growth, while at the same time three houses without ventilators showed an increase in mould growth. Overall (after April 83), of the houses with ventilators, one third had reduced mould growth during the experimental period, while those without ventilators, one third suffered increased mould growth. From this perspective, the ventilators can be said to reduce rather than cure the condensation problems.

3.2 Energy Use

In order to analyse the energy performance, the houses were divided into four groups, namely :

- Better insulated : with ventilators
- Better insulated : no ventilators
- Standard insulated : with ventilators
- Standard insulated : no ventilators



(a) (b)

FIGURE 2. (a) MONTHLY ENERGY CONSUMPTION
(b) MONTHLY AVERAGE INTERNAL TEMPERATURES

The Energy Consumption for each group is given in Figure 2(a) for the period prior to, and after the installation. Figure 2(b) shows the average internal temperatures for the same period. There is no significant change in energy performance attributable to the installation of the trickle ventilators. This implies that there is no energy penalty. The ventilation measurements (REF) showed an increase of about 10 % from the trickle ventilators fully open which as a percentage of the total heat input would be about 2%. Therefore a significant rise in energy use was not expected.

3.3 Window Opening

The window opening surveys were grouped into 6 time periods. For each period the total number of windows open were divided by the number of surveys and the number of houses provides an average window opening score. The results are summarised in Table 2.

TABLE 2. MEASURED LEVELS OF WINDOW OPENING
(average number of open windows per house)

	WITH VENTS	WITHOUT VENTS	DIFFERENCE
Winter 81/82 (before vents fitted)	0.7	0.6	+0.1
Spring 82	0.7	1.1	-0.4
Summer 82	2.0	2.2	-0.2
Autumn 82	1.3	1.4	-0.1
Winter 82/83	0.3	0.5	-0.2
Spring 83	1.6	2.3	-0.7

The Table shows that the houses with ventilators open windows less frequently than those without, about threequarters of a window per house difference by Spring 83. The indication is that there is a period of time over which the occupants learn how to use the new ventilation system, using the trickle ventilators instead of opening windows. This learning process appears to take place over the first year of the measure.

3.4 Occupants Views

The response of the occupants to the ventilators was positively in favour of their use. Occupants were pleased to have the ventilators fitted, believed they helped with reducing condensation and found them a useful alternative to window opening. There were however two factors that attracted criticism, namely, (a) a belief that the ventilators caused draughts, and, (b) their perceived inability to quickly ventilate a room.

(a) Draughts :

Several occupants made reference to draughts from the ventilators during cold and windy weather. The comments from the occupants suggest that 'draughts' were noticed, not as a perception of cold air on the skin, but visually, because of a moving curtain or aurally, because of a ventilator rattling. These problems are rectified if a different ventilator were used, eg the Trimvent (TITON) which defects the air parallel to the plane of the window. It was not possible to use the Trimvent at Abertridwr as a retrofit measure because its fixing would have weakened the existing window frame.

(b) Speed of Reaction :

For occupants to use the ventilators they must believe them to be effective. Some of the interviews with the occupants indicated that the occupants initially expected the ventilators to perform in a similar way to window opening (ie. to clear the air in a room quickly). When this did not happen there was a feeling that the ventilators were of a limited practical value. However, over time, the interviews with the occupants indicated that families learn to use the ventilators by a process of experimentation which shows them what the ventilators can and cannot do, ie. there is a learning curve. Families develop a pattern of ventilation that includes both window opening and the use of ventilators, a pattern that can accomodate the changing requirements of summer and winter as well as the exceptional demands of particular times of day.

Therefore, regarding the above criticisms of the occupants, the first can be avoided by the design of the ventilator and the second disappears over time as the occupant develops new ventilating habits.

4. CONCLUSIONS

In general the use of trickle ventilators improve the internal environmental conditions without incurring a significant energy penalty, namely :

(a) They improve the distribution of ventilation within the internal spatial layout during the heating season, allowing the ventilation rates for individual rooms to be controlled closer to their pattern of occupancy than could be achieved by opening (or not opening) windows.

(b) They reduce the level of condensation mould growth.

The use of trickle ventilators provides a successful method for the control of winter ventilation in well-sealed, energy efficient dwellings. Firstly, producing a well-sealed house results in energy savings. Trickle ventilators then provide the ventilation control necessary to maintain satisfactory internal environmental conditions.

Also, it was found that window opening was reduced during the heating season, though not enough to result in identifiable energy savings.

The installation of the ventilators (to houses on an exposed site) created no difficulties with rain penetration and there was no evidence to suggest that the durability of the window frames had been impaired in any way.

There are now a number of solutions being suggested for ventilation design in modern 'low-energy' dwellings. One such solution is the trickle ventilator configuration discussed in this paper, which has probably been tested more than most others. In the UK, future energy efficient design is likely to be assessed against 'performance standards' which will be based around a finite number of approved solutions. There is therefore the need to select a limited number of available solutions for ventilation design and to thoroughly test each one over a range of operating conditions. A number of approved solutions can then be offered for use by the building industry. This will hopefully reduce the risk of failure in future ventilation design.

Trickle ventilators are now generally recognised as a component part of all the main design solutions for natural ventilation in dwellings.

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DISCUSSION

Paper 1: 'Requirements for adequate user acceptable ventilation installations in dwellings', presented by L. Trepte (Federal Republic of Germany)

H. Granum (Norway)
: What are the possible requirements for ventilation in residential houses in West Germany ?

L. Trepte (Fed.Rep.Ger.)
: *In the German standard DIN 1946, outdoor air flows between 20 and 50 $m^3/h/p$ are recommended with an average of 30 $m^3/h/p$. These recommendations are based on the Pettenkofer number which defines as an upper limit for the carbon dioxide level, a content of CO_2 of 0.15% in the indoor air. Other German standards, e.g. VDI 2088 or DIN 18017 refer to mechanical ventilation and specify for special cases 1 to 1.5 ach. The standards are under revision and the new recommendations will include moisture and body odour aspects. They probably will be defined for different types of dwellings.*

J. Railio (Finland)
: Several researchers and working groups have stated that a minimum ventilation rate of 8 litres/s/person is needed to achieve good indoor air quality. Do you have any comments on this ? Has this been discussed in Annex IX ?

L. Trepte (Fed.Rep.Ger.)
: *8 litres/s/person is a good recommendation for average cases. It corresponds to 30 $m^3/h/p$ and in most cases will avoid moisture, mould growth and body odour problems. However in the case of additional loads, e.g. tobacco smoking or higher moisture emissions, higher ventilation rates are needed. The IEA Annex IX "Minimum Ventilation Rates" report goes into more detail and shows when and why higher rates are needed.*

E. Niskanen (Finland)
: You mentioned overpressurization as a method of preventing the infiltration of radon. What about problems like frost and ice caused by humidity in cold climates ?

L. Trepte (Fed.Rep.Ger.)
: *The radon case mentioned was only an example for possible treatment of a pollutant. For radon primarily the emission into the indoor environment should be avoided. More appropriate measures therefore will be sealing etc. A carefully designed ventilation system can contribute towards reducing the problem.*

More important in most countries, especially in Central Europe, are moisture aspects. Here ventilation is one of the most important measures against the damage caused. The ventilation rate is dependent on the climatic conditions in the country concerned and should be in the order of 0.6 ach.

Paper 2: 'Ventilation, air infiltration and building occupant behaviour', presented by D. Harrje (USA)

P. Favre (Switzerland)
Did you deduce some "typical" profile for window opening from your measurements, or did you get any correlation with the outside climate conditions ?

D. Harrje (USA)
Clearly there are trends in the data on window opening that we have recorded. They certainly follow the general rule that, at the lower temperatures, window opening is less frequent. A formal correlation of the data is contemplated but up to this point has not been carried out.

A. Wilson (U.K.)
In your paper, 53% of people opened the windows because they were too hot. Is this in the winter heating season, the summer cooling season, or both ?

D. Harrje (USA)
The questions were asked in the heating season. People in the housing are elderly and often have low clothing levels. Some occupants wanted winter indoor temperatures at 30°C. This means, to keep some people warm, others find it too hot and therefore people open the windows. However, if the people who were too hot closed their radiators rather than opening windows, the system would be much more efficient.

D. Wilson (Canada)
Why were you concerned with making a quantitative measurement of the window discharge coefficient ?

D. Harrje (USA)
As the paper points out in Figure 7, some of our data comes in the form of window opening. Since so much of the equivalent opening area for an apartment relates to the window opening, the use of an appropriate discharge coefficient allows us to relate these two parameters.

P. Collet (Denmark)
What was the ratio between the infiltration rate due to the behaviour of the inhabitants and the closed house infiltration ?

D. Harrje (USA)
The ratio of actual ventilation rates observed over time compared to the closed window conditions was approximately 5:1. As the data in Figure 5 point out, the ventilation rate varied over a 10:1 range.

H. Granum (Norway)
Do occupants pay individually for heat used ? I would suggest that individual payment might have a major effect on energy use habits.

D. Harrje (USA)
No, the occupants do not pay individually for their heat and yes, it can be a major factor as shown in other studies. However, even without the possibility of altering this situation, it is worthwhile to understand the other causal factors.

Paper 3: 'A preliminary study of window opening in 18 low energy houses', presented by J. Lilly (U.K.)

F. den Dulk (Netherlands)

How does the heating system work ?
(a) Is it only working during the day ?
(b) Do the bedrooms have mechanical ventilation and/or heating systems and are they working at night ?
I need this information in order to understand the results.

J. Lilly (U.K.)

The heating system is described in the paper. It is a warm air recirculation system with 0.5 volumes per hour fresh air supplied when the heating is on. Warm air is provided to every room in the house. Air recirculation occurs through doorway leakage to the central stairwell area where the air heater is positioned. Large air vents to outside and self-closing doors are provided in the kitchen and bathroom to discourage air recirculation from these rooms. The normal heating usage patterns for England are for heating systems to be turned off overnight, so no mechanical ventilation is normally supplied to the bedrooms during the night.

P. Collet (Denmark)

Regarding the constant energy consumption due to opening windows, was this calculated with a constant ach for window opening or had you taken into consideration that the ach could vary quite a lot with the temperature variation ?

J. Lilly (U.K.)

The rough estimation of energy loss due to window opening was obtained by multiplying the mean number of hours of window opening in a month by the temperature difference, and multiplying this by an estimated 3 air changes in the room in which the window was situated. It was only intended to estimate the order of magnitude of this energy loss because we have not yet analysed the data in sufficient detail to be more accurate. No account was taken of the extent to which the windows were open and no account was taken of the variation of ventilation rate due to temperature difference changes during the heating season. A more accurate estimation of the heat losses will be obtained by more detailed study of energy consumption data.

D. Harrje (USA)

Could the lack of window response to the return of milder weather following a cold period in your data be an occupant perception that it was late December, winter was imminent, and further opening of windows was no longer appropriate ?

J. Lilly (U.K.)

Yes, I agree it is likely that the occupants perceived that winter had arrived during a cold spell in November and mentally adjusted to winter window opening routines, even though milder weather followed in December.

E. Niskanen (Finland) — Would you please say something about the external environment of the buildings, particularly as far as air pollution and traffic noise are concerned ? These factors would affect the window opening behaviour of occupants.

J. Lilly (U.K.) — *The test houses were situated in a quiet residential environment in South London. There are no main roads close to the houses, so traffic noise and pollution were unlikely to decrease window opening. General levels of air pollution were also low and are considered unlikely to have any significant effect on window opening in this study.*

T. Lindqvist (Sweden) — I understand that occupants open their windows when they see condensation on the side pane. Do you think their airing pattern will change when better window insulation is provided, i.e. from single to double or triple glazing ?

Could this explain why airing seems to be decreasing since earlier studies ?

J. Lilly (U.K.) — *I would expect that window opening will reduce with lower window U-values due to the consequent reduction in condensation. This is indeed likely to be a contributory factor to the decrease in window opening from earlier studies. Other factors are (1) the fresh air contribution provided by the heating system described and (2) the continuous monitoring system used compared with the intermittent observations of previous studies.*

C-A Roulet (Switzerland) — Usually, energy efficient buildings have good heating systems providing just the power needed to achieve the comfort temperature and no more. Does that explain, at least partly, the large difference you have observed between your results (on a low energy building) and others (on a "normal" building) where occupants open the windows to control the indoor temperature ?

J. Lilly (U.K.) — *The heating systems in these houses were modulating warm air systems with a uniform efficiency over a wide range of system loading. The systems' efficiencies were therefore not critically dependent upon perfect system sizing. The sizing of the heating systems therefore followed the normal UK practice of system oversizing to provide fast warm-up times necessary for intermittently operated heating systems. Therefore, critical heating system sizing cannot be considered as a reason for the differences between previous results and those obtained in this study.*

<u>Paper 4</u>: 'Occupants influence on air change in dwellings', presented by B. Kvisgaard (Denmark)

J. Railio (Finland) — In mechanically ventilated buildings, is it possible for the occupant to increase or decrease the <u>mechanical</u> ventilation ? If yes, how do people operate the system ?

How is the central ventilation in high-rise buildings generally operated ?

B. Kvisgaard (Denmark) — *In single family houses you usually can choose between normal and forced ventilation. Forced ventilation is only used a few hours each day. In high-rise buildings there is normally two levels of the fan. These are normally operated with a central clock.*

P. Levin (Sweden) — When measuring the "base case" ventilation, the vent stacks were closed which means that the natural ventilation system was not working. Did you investigate the occupants' operation of these vents and proportional increase in air change rate because of this ?

B. Kvisgaard (Denmark) — *Under basic air change measurement, all vents were closed, but in the bathroom, kitchen and toilet there was always a free opening area of 20% of the full opening area in the vent. The minimum opening area of 20% is stated in the building code. Occupants often closed the vent in the bathroom because of problems with cold draughts. The increase in air change rate, due to opening of vents, was measured but the effect was found to be small.*

H. Granum (Norway) — Regarding your conclusion that the ventilation was too small in 20% of the houses, is this conclusion based upon health considerations, condensation risks or on formal requirements in the building code ?

B. Kvisgaard (Denmark) — *The conclusion was based upon observations in the dwellings. 20% of those measured had condensation problems on double-glazed windows. One of the dwellings even had problems with condensation on a triple-glazed window in the bedroom.*

O. Nielsen (Denmark) — Your last statement in your conclusion was "The air change regulation is not sufficient". What do you mean by this ?

B. Kvisgaard (Denmark) — *The occupants have insufficient possibilities to adjust the air change rate in the dwellings. Windows cannot be opened in small steps; you must often choose between fully opened or fully closed windows. Vents are often too small to increase the air change to an acceptable level.*

F. den Dulk (Netherlands) — During the measurements, several different types of houses were examined. What about the relationship between the type of house/dwelling and ventilation behaviour. If there is a relationship, maybe you will also find other relationships in ventilation behaviour, number of occupants, etc.

Note: In 12-storey houses, there is a very high basic air change rate due to wind.

B. Kvisgaard (Denmark) — *In a more homogenous measurement group, it would be easier to find relationships between air change rate and outdoor temperature for example. We will try to get more measurements into the database in order to increase our chances of finding relationships.*

D. Wilson (Canada): Why did you not include varying windspeed as one of the factors which influence the basic air change rate ?

Did you try plotting up the difference between the basic air change rate and the occupied air change rate, rather than the total ? In particular, do you think occupants add a fixed factor to the basic air change or multiply the basic air change by a fixed amount ?

B. Kvisgaard (Denmark): *In this study we were not interested in factors which influenced the basic air change rate.*

No, we did not make plots of the difference between basic and total air change. I think the occupants are more likely to add a fixed amount to the basic air change rate.

Paper 6: 'Ventilation and occupant behaviour in two apartment buildings', presented by M. Modera (USA)

W. de Gids (Netherlands): Did you measure pressure distribution ? You mentioned a symmetric pressure distribution, suggesting low outside infiltration rates, for wind direction parallel to the building. We have not found these effects in our investigations.

M. Modera (USA): *Two points should be made in response to this comment. First, under parallel wind conditions, some infiltration will be induced due to the gradient of wind speed along the height of the building. Because the wind speed is higher at the upper storeys, some flow will be induced even when each storey has the same pressure coefficient. The second point is that the houses in the Netherlands have ventilation shafts which terminate as chimneys on the roof. These chimneys will induce larger flows under parallel flow conditions.*

D. Wilson (Canada): The leakage area from blower door tests gave about 40% in the apartment to the outside. Did you find that 40% of the total flow into or out of the apartment was outside air ?

M. Modera (USA): *The percentage of the total flow into an apartment that comes from outside depends on the location of the apartment and the weather. Under stack-dominated conditions, 100% of the air entering a first-storey apartment comes from outside. On the third storey, all the incoming air comes from the second storey apartment, whereas the second storey gets approximately 50% of its air from inside and 50% from outside. As the wind speed increases, the fraction of air coming from outside to the upper storey apartments increases (up to almost 100% under wind dominated conditions). Under wind dominated conditions it is possible for a fraction of the air entering the first-storey apartment to come from the upper apartment. This is due to the wind speed profile. Finally, under wind dominated contions, the third-storey apartment can be depressurized relative to the lower storeys depending on the relative magnitudes of the wall and roof leakage. The larger the roof leakage, the larger the extent of depressurization becomes.*

P. Collet (Denmark) — Would it be true to say that this paper shows you cannot predict the ach without measuring it ?

M. Modera (USA) — *Although continuous ventilation measurements could confirm our interpretation of temperature profiles, such measurements would increase the cost of the study significantly. The objective of this study was to examine possible correlations between building characteristics and occupant behaviour. Ventilation measurements would not be economically justified in this case. On the other hand, ventilation measurements would be quite useful in more detailed studies which monitor window opening, indoor temperature and wind speed. They could resolve important questions about the actual flow rate through open windows.*

W. de Gids (Netherlands) — Can you elaborate on your multi-disciplinary approach and the results you get ?

M. Modera (USA) — *The multi-disciplinary approach employed consisted of social science techniques (interviews) in combination with hard science techniques (monitoring and diagnostic/simulation). By performing all three types of investigation simultaneously, the analyses and conclusions drawn from each technique can be corroborated. In this particular project, the multi-disciplinary approach allows us to have more confidence in our conclusions about ventilation and occupant behaviour in these buildings.*

Paper 7: 'Inhabitant behaviour with regard to mechanical ventilation in France', presented by D. Bienfait (France)

K. Hallgreen (Denmark) — You have only mentioned manually controlled ventilation. Can you tell us something about the automatically controlled system (humidity) ?

D. Bienfait (France) — *Humidity controlled systems have been commercially available for two years. For the moment they cover about 5% of the mechanical ventilation market, but new developments are still in progress and this figure could increase.*

Heat loss reduction through air renewal is expected to be in the range of 30% with respect to a conventioned ventilation system.

D. Harrje (USA) — Please explain further the details of your air inlets and why they cannot be adjusted.

To further control exhaust rates, have you considered variable speed fan exhaust ?

D. Bienfait (France) — *Air inlets in France are self-regulated against pressure difference. It means that, for a given range of pressure (usually 10 to 100 Pa) the flow rate remains constant. The flow rate is easily achieved by a flexible sheet which automatically reduces the air section as the pressure difference increases. The whole device is very simple and* *its cost is in the range of 4 Fr. According to Building Regulations, adjustable air inlets are not forbidden. However, the habit for the time being is to use non-adjustable air inlets in order not to disturb the flow rates in the exhaust ducts when tight buildings are considered.*

Variable speed fans are currently used to control exhaust air flows in single family houses only.

H. Granum (Norway)
How airtight are your houses ? Can you give any figures of the air leakages by a given pressure difference ?

D. Bienfait (France)
Results of recent measurements on houses are as follows:

Air leakage under 10 Pa

Multi family houses	: *extreme values*	:	*40 and 180 m³/h*
	typical value	:	*90 m³/h*
Single family houses	: *extreme values*	:	*100 and 150 m³/h*
	typical value	:	*200 m³/h*

The trend for new constructions is to reduce these values.

Air inlets total flow rate under 10 Pa : *120 m³/h*

P. Hartmann (Switzerland)
Is there any calculation made for energy consumption of buildings where you have to prove a certain consumption before getting building permission ?

D. Bienfait (France)
Yes, there are strong incentives, according to codes, not to exceed a certain level of heat loss.

P. Hartmann (Switzerland)
You explained that most new houses have mechanical ventilation systems. What is the additional heating ? How do people pay for the heating ?

D. Bienfait (France)
In single family houses percentages are roughly as follows:

- *electrical heating : 60%*
- *gas heating : 30%*
- *others : 10%*

Heating is always independent of the ventilation system. In multi family houses, the bill is paid directly to the gas or electricity company when heating is individual. With collective heating it is usually paid with the rent to the landlord.

Paper 8: 'Ventilation heating system of small houses', presented by J. Laine (Finland)

M. Holmes (U.K.)
The system appears complex. Does it need special maintenance, particularly with regard to air flow regulation ? Do you think any training is required for installers or, indeed, users ?

J. Laine (Finland)

The ventilation heating system is a very simple, advanced system. It is possible to achieve good indoor air, low noise level, good environment, sound insulation and good energy efficiency. The system also gives better changes to meet the inhabitants' expectations and interactions on heating and ventilation systems. All ventilation devices need maintenance. Special maintenance involves changing the air filters, cleaning the heat recovery device and the air flow ratio regulator about once a year.

The training required is less than that needed for other completely mechanical systems, including heat recovery and heating because of the possibility to preadjust the flows and automatically operate the system.

Passive ventilation needs more care and maintenance than advanced systems. With the official requirements and minimum equipment, it is possible to guarantee only the minimum acceptable level of indoor air.

K. Hallgreen (Denmark)

Will there be a risk of overpressure in the house if you have a manually controlled exhaust fan ?

Do you think that the inhabitants can overlook the consequences of the manual control of the exhaust fan ?

J. Laine (Finland)

No, there will not. The flow ratio regulator automatically controls the outdoor air flow according to the exhaust air flow. The difference between exhaust air flow and outdoor air flow remains almost constant with the whole manually controlled flow range.

Yes, it is possible because the individual exhaust terminal devices are equipped with a facility for increasing air flow locally.

D. Harrje (USA)

In the example you have shown, -9 Pa at the first floor, have you considered that this negative pressure may cause increased radon problems in radon soil locations ?

J. Laine (Finland)

In cold climates, it is necessary to maintain negative pressure in the house to avoid condensation problems on windows. At cold outdoor temperatures, the thermal forces are strong and at the first floor the negative pressure increases. Houses situated in radon soil areas have ventilated spaces with large air openings under the first floor to avoid radon problems.

W. de Gids (Netherlands)

The theme of the conference is occupant interaction with ventilation systems. Can occupants influence their outside fresh air flow rate ? If so, how do they control that flow ?

J. Laine (Finland)

When the occupants increase or decrease their air flow, the flow ratio regulator of the outdoor and exhaust air flows automatically increases or decreases respectively the outside fresh air flow. In this way, the difference *between exhaust air flow and the outside fresh air flow remains amost constant within the whole flow range. Total ventilation air flow can be increased with the control knob in the hood by increasing the rotation speed of the exhaust fan.*

P. Hartmann (Switzerland) — Is there a tendency to invoke legislation that individual room controls (temperature, ventilation rate) must be installed ?

J. Laine (Finland) — *There are no official requirements at present, nor in the foreseeable future, for the installation of individual temperature and ventilation controls. The official requirements are based on a standard for a minimum acceptable level of indoor air. Therefore, good indoor air will not be guaranteed by government regulations, but efforts have been made in order to define voluntary recommendations. These recommendations will most probably also include the possibility for individual control of temperature and ventilation. For example, a suitable temperature range in winter will be 21 ± 2°C.*

It is also worth mentioning that, although individual control incurs some extra investment cost, many inhabitants, users and builders are already prepared to pay for good indoor air and good air conditioning because of its proven positive influence on human health, comfort and productivity.

Paper 9: 'User controlled exhaust fan ventilation in one-family houses', presented by A. Blomsterberg (Sweden)

D. Harrje (USA) — You have mentioned that one house did not have a vapour barrier and thus had 3 ach at 50 Pa, compared with 1.6 ach at 50 Pa for the others. Did this house perform in a different way from a ventilation or moisture standpoint ?

A. Blomsterberg (Sweden) — *The tracer gas technique was never used in the house without a vapour barrier.The air flow through the fan was measured once using a permanently installed (in the duct before the fan) air flow measuring device. All 18 houses have the same exhaust air flows. According to my 5th AIVC Conference paper, a house with exhaust fan ventilation should be tighter than 3 ach at 50 Pa (including vents). Ideally this particular house should have been tighter. The moisture content inside the walls, the floor and the ceiling has been measured monthly by analysing pieces of wood. No difference has been observed between this house and the other houses.*

D. Harrje (USA) — It was my impression from past studies (including your own in 1982) that short circuiting took place whenever the tightness strayed from very low leakage rates (near to 1 ach at 50 Pa).

J. Railio (Finland)

You found hardly any influence on bedroom air change rates of exhaust vents in bedrooms. Were the bedroom doors open or closed ? Could bedroom ventilation be improved by the possibility of concentrating the exhaust, e.g. simply by one damper, in order to have most of exhaust from bedrooms at night ?

What kind of user education/information was given to the inhabitants ?

A. Blomsterberg (Sweden)

The bedroom door was closed in two bedrooms and open in one. It would make sense if the exhaust air flow could be concentrated as you suggest. The question might be whether you can teach the occupants to do this. Alternatively, the effect could be tested of enlarging the inlet vents in the bedrooms of the houses with parallel flow.

Each house owner was given an owner's manual in which they were told, for example, how to operate the ventilation system. The manual explained why the inlet vents should be open, etc.

P. Hartmann (Switzerland)

Please explain how the ventilation efficiency measurements were carried out in these inhabited buildings ?

A. Blomsterberg (Sweden)

All the ventilation measurements were made in unoccupied houses. In each house the air flow through the exhaust fan was measured once using a permanently installed duct flow measuring device. In two houses the constant concentration tracer gas technique was used to monitor the supply of fresh air to individual rooms during 4-5 days. At the end of these measurements the supply of tracer gas was turned off and additional measuring points were added. The decay of the tracer gas was then monitored at 17 different measuring points for at least 1 hour. From this final measurement the ventilation efficiency was calculated.

P. Collet (Denmark)

It is really nice to see a paper where the philosophy is to simplify the mechanical ventilation, but I think it is imperative to measure the ach in those 2 + 18 houses when they are occupied. Will you be doing that next year ?

A. Blomsterberg (Sweden)

The idea behind the whole project was to see how far you can get using simple techniques throughout the construction of a one-family house. The house was to be energy efficient with a good indoor climate and less expensive than conventional houses. Today we have a fairly good idea as to how the occupants are using the exhaust fan, the windows and the supply vents in the 18 houses. We will therefore probably not monitor the ventilation using tracer gas when the houses are occupied, although it is a good idea.

C-A Roulet (Switzerland)

Did you have a mixing fan for tracer gas during the efficiency measurements ?

A. Blomsterberg (sweden)

Mixing fans were used while we were creating a constant concentration of the tracer gas throughout the house. Once the efficiency measurement, i.e. the decay measurement, started all the mixing fans were turned off.

O. Nielsem
(Denmark)

Talking about indoor climate, have you calculated the expected concentrations of air humidity and CO_2 in the main bedroom, with the very low outdoor air coming in ? I think you will exceed the threshold limit for a workplace area.

A. Blomsterberg
(Sweden)

No, I have not done that yet, but I will.

Paper 10: 'Ventilation and indoor air quality in new Norwegian houses', presented by H. Granum (Norway)

C-A Roulet
(Switzerland)

Several papers show that some people sleep with the windows open all year round, as I do. Do you know any regulation taking that into account, or any existing building having insulation between bedrooms and other rooms, and an airtight bedroom door ? I know of no such regulation, a fact which I find amazing.

H. Granum
(Norway)

We have no requirement for thermal insulation in interior walls and doors in Norway.

P. Hartmann
(Switzerland)

Do Norwegian building regulations have strict emission control on products ?

H. Granum
(Norway)

No "strict" control. The most commonly used surface material is gypsum and fibre board and only partly carpeted floors. My conclusion is perhaps too general. It was based mostly on the observed projects in Trondheim where no problems were noted.

J. van Dongen
(Netherlands)

You found a relationship between energy consumption and use of windows in the bedrooms. In my projects which I studied in Holland, I did not find this relationship. However, the heating provisions are seldom used on average. Do people in Norway usually heat their bedrooms ?

H. Granum
(Norway)

In many cases, bedroom doors are kept open towards the rest of the house even when the bedroom windows are open. Cooling of the construction also requires more heat in the morning when the room is reheated.

O. Nielsen
(Denmark)

You said there were no indoor climate problems, even in tight houses in Norway. In Denmark we have many indoor climate projects and they show that the more you investigate, the more problems you find. We have even found several sources of pollution from, for example, wood. So maybe your lack of indoor climate problems in Norway is because you carry out few indoor climate investigations. In Norway you also say there appear to be few complaints but this could be because people have nowhere to lodge their complaints.

H. Granum
(Norway)

There are very few complaints in any case but I agree that my conclusion regarding chemical pollutants was too general. We have performed real measurements in only one project consisting of 14 extremely airtight houses. The material used in these houses may not be representative.

Paper 11: 'Influence of the meteorological conditions on the inhabitants behaviour in dwellings with mechanical ventilation', presented by E. Erhorn (Federal Republic of Germany)

J. van Dongen (Netherlands): The difference in use of windows between mechanical and non-mechanical ventilation may be explained by the impossibility of being able to set the windows ajar.

Paper 12: 'A sociological perspective on tenant behaviour with regard to domestic ventilation - an example at Lausanne', presented by P. Rossel (Switzerland)

D. Harrje (USA): The question of metering for heating energy in a multi-family building is very complex:

- where you are located in the building, i.e. high, low, south, north.
- the temperature preferences of neighbours; old, young, working couples, etc.

How can one make it equatable if each is assigned a similar energy target ?

P. Rossel (Switzerland): *I think there is no absolutely satisfactory answer. We thought about a sophisticated system of tele-commanding the heating variations, apartment-by-apartment and room-by-room with the possibility of the tenants interacting with the driving of the part of the device that concerns them. But this again raises the problem of energy stealing.*

One way would be to associate such a device (which satisfies people's need to control their environment) with coefficient (related, for instance, to the position of the apartment) and a minimal common interior temperature. This would put the responsibility of equipping themselves with heating devices on to those who want a higher temperature than, say, 21°C, with the possibility of losing energy to their neighbours. It is almost a new moral approach, very far from actual practice, which aims to satisfy the 'heat greedy' and level the whole building on that target.

E. Niskanen (Finland): You say in the introduction that technology (designed by engineers) often comes up against one basic and paradoxically unpredictable variable - the behaviour of occupants.

Everybody wants simple solutions to complicated problems. However, the only way to satisfy the needs of an individual occupant is to apply more automation with greater adjustability. If occupants want the option of spatio-temporal control, which means better air quality and comfort etc., they have to accept more advanced technology in the same way as they have learned to live with, say, the television.

Paper 14: 'Measurement of carbon dioxide of the indoor air to control the fresh air supply', presented by I. Fecker (Switzerland)

P. Wouters (Belgium)
Does the difference in measurement technique explain the high sensitivity of the people outside a room to the body odour in the indoor air ?

I. Fecker (Switzerland)
The higher sensitivity to odour of the people outside a room as opposed to the apparent insensitivity of those inside, is based on the adaptation of the sense of smell to odours. Measurement techniques should not have any influence on the result.

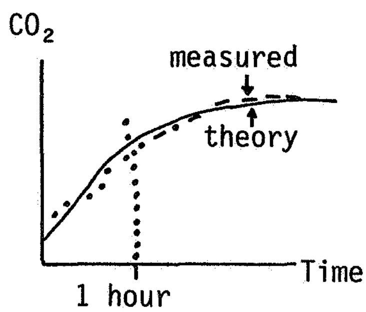
C-A Roulet (Switzerland)
Did you measure also the relative humidity ? If so, did you find a relationship between CO_2 and H_2O content ?

What is an "air quality sensor" ?

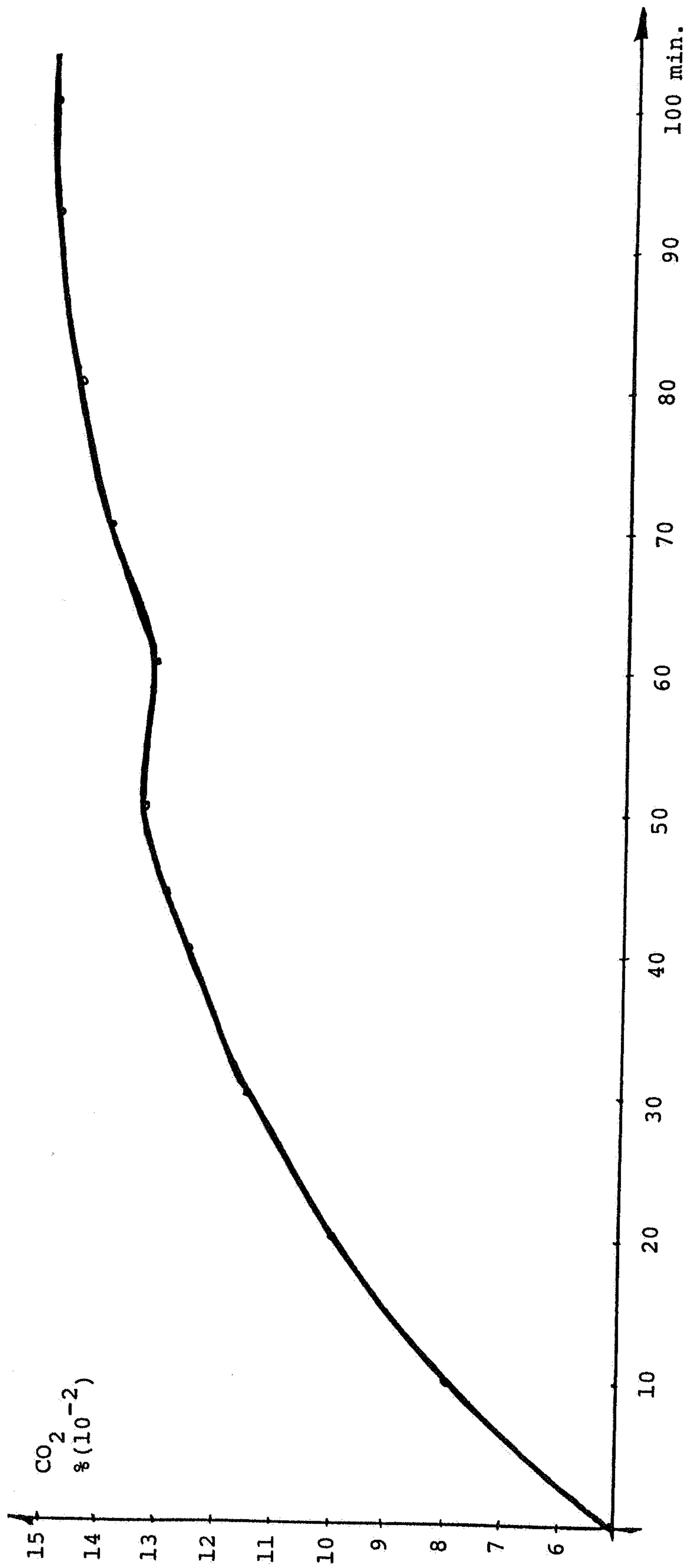
I. Fecker (Switzerland)
I also measured the relative humidity. If the outdoor change rate is small, there is a relationship between carbon dioxide and humidity, because both of the mentioned substances are exhaled by man. In the case of the climatic chamber experiments, the relative humidity increased, while it was held constant in the lecture theatre.

A metal oxide inserts certain molecules in the crystal lattice, e.g. water, carbon monoxide and others. Therefore the conductivity of the oxides changes depending on the concentration of the substances in the air. This chemical process is reversible.

J. Railio (Finland)
You mentioned that the CO_2 concentration was measured continuously. For design of ventilation in temporarily occupied spaces, such as lecture theatres, the curve of increase in CO_2 concentration might be very useful. For example:



I. Fecker (Switzerland)
The following figure shows the increase in carbon dioxide concentration of experiment No.33 (65 students; 16 m³ outdoor air/person/hour).



CO2
%(10-2)
15
14
13
12
11
10
9
8
7
6
10
20
30
40
50
60
70
80
90
100 min.

Paper 15: 'Gravity driven flows through open doors', presented by D. Kiel (Canada)

H. Phaff (Netherlands)

Does the plastic foil, used for separating parts of the house, have any influence on the warm-up time of the incoming cold air ? Comparison should be made between the heat flow from a stone (concrete) wall or the plastic foil into the room air, especially when the door is open for long periods.

D. Wilson (Canada)

In our tests, the door was open for a short time, typically 10 seconds, after which fans were used to mix the cold air with the room air. All this took less than a minute and heat transfer through any type of barrier was negligible in the short time interval.

M. Sherman (USA)

You did not mention the effect of wind on the exchange rate. Could you elaborate on the interaction of wind and temperature ?

D. Wilson (Canada)

The doors were sheltered from direct wind impingement by a nearby building. The wind induced turbulence near the entry promoted mixing between the incoming outdoor air and the outgoing room air which caused the net inflow to decrease. This led to the remarkable result that the net inflow actually decreased when the wind speed increased. It was also found that this wind turbulence flow "reduction" was most important for small temperature differences as might be expected from mixing layer stability considerations.

Paper 16: 'The use of passive ventilation systems for condensation control in dwellings and their effect upon energy consumption', presented by R. Edwards (U.K.)

W. de Gids (Netherlands)

Have you studied backdraughting in your passive system ? If so, what was the effect in terms of draught problems ?

How does the system work with snow on the roof ?

What is the net area of the rooftile in relation to the duct cross area ?

C. Irwin (U.K.)

We have encountered "flow reversal" in the passive ventilation ducts leading to problems of draughts in the kitchen and bathroom.

The effect of snow on the roof may cause problems. However, the roof terminal selected should hopefully not suffer from snow blockage.

The duct cross sectional area is 15,000 mm², the net area of the roof tile is approximately 1,000 mm².

R. Stephen (U.K.)

I notice that the house you used was built with a conventional fireplace and chimney. Do you think it would be worth comparing the air flow up the chimney with the flow up the passive ventilation ducts ? I accept that the chimney is not in a room where moisture is produced.

C. Irwin (U.K.) *Yes, we feel that the chimney would seriously effect the performance of the passive ventilation system installed in this house. To evaluate this effect we are going to carry out a series of measurements with the chimney in use.*

P. Collet (Denmark) Your paper gives rise to some questions:

You explain that opening a door will increase the flow but spread the moisture throughout the house. Why do you not have an opening underneath the door which allows a one-way flow into the vented room ?

With the passive ventilation system described, the pipe should rise over the top of the roof to minimise the risk that the pipe could happen to be in a pressure zone.

Did you have a negative flow in the ducts when using the fireplace ?

C. Irwin (U.K.) *A low level opening/door grille will help improve the passive duct performance. However, from our experience there would be resistance from building designers in allowing such an opening in the door.*

Yes, a straight pipe terminal above the ridge line should ensure the system is in suction. However, this study was carried out with a low profile roof terminal to enable comparison with existing work in the U.K.

With the firplace in use a severe reduction in the passive ventilation system performance was noticed.

K. Johnson (U.K.) I am very disappointed, as I am sure you are, with the low flow rates recorded in your passive ventilation system, especially in view of the great potential such a system would have in solving ventilation problems in the U.K. Have you considered what features of your installation could throttle the flows ? In particular, have you looked at ways of avoiding the change of cross-section of the ducts and the severe bends of the flexible connection to the outlet ?

C. Irwin (U.K.) *The most significant factors that affect air flows are (1) air inlet grilles and (2) roof terminal. As a general statement, flexible pipe bends should also be kept as gradual as possible. To avoid problems with severe bends of the flexible ducts, this installation has been modified by connecting the flexible ducts to ridge vents. This provides a more gradual bend in which to terminate the system. However, the flow rates are still quite small.*

R. Dietz (USA) Moisture generation and condensation are very often a local zonal problem, yet most papers were addressing the use of entire zonal ventilation which has a whole house energy penalty. Has any consideration been given to the concept of either exchanging air with another zone that is drier or using a temporary temperature increase in the wet zone such as that from a timed heat lamp ?

C. Irwin
(U.K.)

Exchanging air with adjacent zones in a house is, in our opinion, the only method of providing adequate ventilation rates in high moisture input areas, i.e. kitchen, bathroom, when using a passive ventilation system in an airtight house. However, if doors are left open in a house then the large, two-directional airflows in the door opening will encourage air/moisture exchange to adjacent areas in an occupied house.

Paper S.1

'Influence of night-time ventilation reduction on indoor air quality in Danish blocks of flats', presented by O. Nielsen (Denmark)

P. Collet
(Denmark)

If you carried out another sort of calculation, would it not show that if you calculated the RH only due to the exhaust system, you would have had a significant rise both in the RH and the absolute concentration ? Thus showing that the behaviour of inhabitants would be the cause of the lack of significant rise in RH due to reduced ventilation.

O. Nielsen
(Denmark)

The indoor humidity content depends on other parameters than ventilation. You are asking about, e.g. the production of water in the flats. Some of the parameters I have asked for and some I have not, e.g. details of the inhabitants' washing routine. I have tried to make a mathematical model for the humidity inside on the basis of my results, but I have not been successful.

C-A Roulet
(Switzerland)

Your results show that, in principle, the ventilation rate can be even more reduced. What is the ventilation rate in air changes/hour in 100% of your buildings ?

O. Nielsen
(Denmark)

The demands for mechanical exhaustion in multi-family houses in our building code is in Table 1 of the paper. It will equal an air change in the flats participating in the project of about 0.9 ach. The actual measured exhaustion values were:

	Kitchen	*Bath*	*Toilets*
Building 1	*-35 p.c.*	*-25 p.c.*	
Building 2	*-48 p.c.*	*-22 p.c.*	
Building 3	*-11 to +33 p.c.*	*-59 p.c.*	*-58 p.c.*

J. Railio
(Finland)

Was bedroom air change rate measured or can that be estimated, knowing the measured humidity and occupancy ?

O. Nielsen
(Denmark)

No air change measurements were done, only the exhaust flow volumes from the exhaust air teminal devices. Only in the six cases with CO_2 measurements in the bedrooms do we have information as to whether the door from the bedroom to the rest of the apartment was open or closed.

D. Harrje
(USA)

Is it not true to say that the wooden block moisture measurement technique misses the rising relative humidity in the bedrooms during the night due to the occupants (there being no "real time" measurement in that apartment location) ?

O. Nielsen (Denmark)

You are right if you go for peak values. For many air pollutions you actually do so, but for the humidity you do not. A health risk I connect with air humidity is, for example, allergic diseases due to house dust mites. The best way to get rid of the mites is to dry them out. In other words, you should have lower humidity than 45 p.c. in the winter months.

Paper S.3

'A detailed statistical analysis on 2800 social houses of the relationship between living patterns (e.g. window use), energy consumption and humidity problems', presented by P. Wouters (Belgium)

P. Collet (Denmark)

How do you calculate the flow through a wide open window (1 m/s → 3600 m^3/h per ml) ?

How do you take into account that two open windows (up/down or opposite sides) will magnify the flow through one window (the principle being that you cannot blow air down a bottle) ?

R. Stephen (U.K.)

In your estimates of increase in ventilation rates due to window use, you seem to have assumed single sided ventilation and not cross ventilation. In the apartments this may be correct, where the windows in one apartment are on one side of the block only. In houses/dwellings I think you should assume cross ventilation, so the air flow rates through the windows will be much greater. Can you comment on this please ? Was there more "building damage" in the apartments than in the dwellings ?

P. Wouters (Belgium)

It is true that the assumption of one sided ventilation underestimates the air flow in certain cases. However, our figures are an average for all the rooms and all the cases - the small window in the toilet as well as the two large windows in certain apartments. We believe that in winter cross ventilation is not as common.

The relationship with damage will be analysed soon.

E. Niskanen (Finland)

The means, medians and averages are tools for marketing managers, the variations are more important for designers. People are individuals and allowances should be made both for young and old, sick and healthy, poor and rich. Individual comfort presumes flexibility in design and should not be overlooked for reasons of energy saving.

D. Harrje (USA)

Under severe weather conditions one experiences quite different window opening patterns. For example, in air-conditioned homes windows tend to be closed and, with low stack effect, the summer ventilation rates are only 1/2 to 1/3 of winter values - often only .1 to .3 ach. Using windows to improve summer comfort, with temperatures moving to 30°C or more, windows are opened in the evening and at night, and closed before mid morning. Shades are pulled down to limit solar gain and the thermal mass of the building with very low ventilation rates is used to improve occupant comfort during mid day and afternoon periods.

Paper S.4 — 'Effect of instructions to inhabitants on their window behaviour', presented by J. Phaff (Netherlands)

D. Harrje (USA)
With your marvellous database, have you attempted to evaluate such parameters as age of occupants, effect of actual inside-to-outside temperature difference, and the influence of the time constant of the building, i.e. delay of full impact of a sudden increase or decrease in outside temperature change ?

J. Phaff (Netherlands)
Additional variables have been gathered by enquiry and diary. These will also be used in modelling window use for individual inhabitants in the next few months as there was no possibility for us to continuously measure building temperature. These figures will be derived from the temperature measurement during the enquiry and from a thermal model of every apartment. Evaluations will continue until 1987.

O. Nielsen (Denmark)
You gave the inhabitants some instructions about window opening to avoid too much ventilation. On which basis did you give these instructions ?

J. Phaff (Netherlands)
The actual flow has been estimated by addition of the background flow and the single open window flow. This flow has been compared with the demand for ventilation from the Dutch standard for ventilation with an assumed number of inhabitants and activities in all rooms. Per room we get a result in three classes: less ventilation, right ventilation, too much ventilation. The ventilation example would be able to move both "less" and "too much" groups to the "right ventilation".

Paper S.5 — 'Inhabitants behaviour with respect to ventilation', presented by J. van Dongen (Netherlands)

E. Niskanen (Finland)
You mentioned three factors of basic importance: security, traffic noise and outdoor air pollution, which presumes filtration. The last mentioned largely limits use of the ordinary windows in ventilation, particularly in the town areas with heavy traffic. As a designer, I fully agree that the technological solutions should respond to the needs of the occupants in this respect, which means that a part of the replacement air should be controllable and filtered, the rest of it coming through the envelope as normal. The windows should be used only in the case of exceptional loads.

J van Dongen (Netherlands)
I agree with your comment. It must be stressed that, with respect to the technological solutions, much attention ought to be paid to the "user friendliness" of the provisions, especially with regard to cleaning filters.

J. Phaff (Netherlands)
You stated that heat loss from bedrooms would have been lower because the radiator is switched off when the window is open. In early studies this heat flow from bedrooms has been proved to exist even with radiators off. The influence of switching off the radiator while the window is open is less than 20% of the heat loss. As Mr Granum mentioned, insulation of bedroom walls may change that.

J van Dongen (Netherlands) *In the dwellings, in the cases in Huizen and Schiedam, a significant correlation is found of about .40 between the number of radiators used and the energy consumption. On average the heating in the bedrooms is not often used in the Netherlands. I have to say that in Huizen a heavy floor/ceiling (no insulation) between the bedroom and the living room is built. Complaints were expressed about the long warming-up time.*

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