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# Inhabitant Behaviour with Respect to Ventilation – a Summary Report of IEA Annex VIII

March 1988

**Air Infiltration and Ventilation Centre**
Old Bracknell Lane West, Bracknell,
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# Inhabitant Behaviour with Respect to Ventilation – a Summary Report of IEA Annex VIII

Carine Dubrul

(Operating Agent - IEA Annex VIII)

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## PREFACE

International Energy Agency

Effective cooperation amongst nations and the development of new technologies to reduce dependence on fossil fuels are critically important elements of a sound energy future. Agreement by twenty-one countries to cooperate on energy policy is embodied in an International Energy Programme, developed in the wake of the 1973/74 energy crisis and administered by the International Energy Agency (IEA), an autonomous body within the OECD.

Energy Conservation in Buildings and Community Systems

As one element of the energy programme, the IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognised in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme 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 that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *):

I. Load Energy Determination of Buildings *
II. Ekistics and Advanced Community Energy Systems *
III. Energy Conservation in Residential Buildings *
IV. Glasgow Commercial Building Monitoring *
V. Air Infiltration and Ventilation Centre
VI. Energy Systems and Design of Communities *
VII. Local Government Energy Planning *
VIII. Inhabitant Behaviour with Regard to Ventilation *
IX. Minimum Ventilation Rates *
X. Building HVAC Systems Simulation
XI. Energy Auditing *
XII. Windows and Fenestration *
XIII. Energy Management in Hospitals *
XIV. Condensation
XV. Energy Efficiency in Schools
XVI. BEMS - 1: Energy Management Procedures
XVII. BEMS - 2: Evaluation and Emulation Techniques

XVIII. Demand Controlled Ventilating Systems
XIX. Low Slope Roof Systems
XX. Air Flow Patterns within Buildings

Task VIII. Inhabitants' Behaviour with respect to Ventilation

Although some research has already been undertaken on the problem of inhabitants' behaviour with regard to ventilation, none has gone as far as to assess whether and how ventilation behaviour can be modified in order to save energy whilst taking into account the conflicting requirements of energy conservation and adequate indoor air quality. The main objectives of this annex are:

1. To determine the behaviour of inhabitants and to correlate it to the outdoor and indoor climate.
2. To estimate the amount of energy lost due to such behaviour.
3. To study the motivation behind inhabitants' behaviour.
4. To study whether such behaviour can be modified and, if so, to estimate the resulting energy savings.

The University of Namur (Belgium) was responsible for the operation of this task. The Operating Agent was Ms. Carine Dubrul.

Participants in Task VIII.

| | |
|---|---|
| Belgium: | * Belgian Building Research Institute (CSTC-WTCB) financed by the Prime Minister's Office - Science Policy Programming (SPPS-DPWB).<br>* University of Namur (Facultes Universitaires Notre-Dame de la Paix) (Operating Agent) financed by the Prime Minister's Office - Science Policy Programming (SPPS - DPWB). |
| Germany: | * Dornier Systems GmbH financed by the project management for biology, ecology and energy (PBE) of KFA Julich GmbH on behalf of the Federal Ministry for Research and Technology of the Federal Republic of Germany (BMFT). |
| Switzerland: | * Office Federal de l'Energie |
| The Netherlands: | * TNO, Division of Technology for Society, Department of Indoor Environment.<br>* TNO, Institute for Preventive Health Care.<br>(Both financed by the Management Office for Energy Research.) |
| United Kingdom: | * Building Research Establishment. |

## FOREWORD

This report is based on a summary of the work of IEA Annex VIII - "Inhabitants' Behaviour with respect to Ventilation", and has been edited by the Air Infiltration and Ventilation Centre for publication as an AIVC Technical Note. Contributors to Annex VIII were:

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United Kingdom:
- P. Jackman; Building Services Research and Information Association;
- P. R. Warren; Building Research Establishment.

The complete results of this study are published in three volumes and are available from:

The University of Namur
Facultes Universitaires Notre Dame de la Paix
NAMUR
Belgium

The numbering of references in this publication coincides with that of the full report.

## LIST OF SYMBOLS

| Quantity | Symbol | Unit |
|---|---|---|
| Air change rate | $n_{ach}$ . $n_{occ}$ | $h^{-1}$ |
| Air flow rate | $q_v$ | $m^3/s$ or $dm^3/s$ |
| Air density | $\rho$ | $kg/m^3$ |
| Air leakage value | C | $m^3/s\ Pa^n$ |
| Angle | $\theta$ | — |
| Area | A | $m^2$ |
| Coefficient | J | — |
| Coefficient | B | — |
| Concentration | c | kg/kg |
| Constant | K | — |
| Constant | $\alpha$ | — |
| Correlation coefficient | r | — |
| Degree days | DD | d.K |
| Energy loss | Q | J or MJ |
| Efficiency | $\eta$ | — |
| Exponent | n | — |
| Heat capacity | $c_p$ | J/kg.K |
| Heat flux | Ø | W |
| Heating value | H | KJ/Kg or $KJ/m^3$ |
| Heat transmission coeff. | U | $W/m^2K$ |
| Height | h | m |
| Number | N | — |
| Pressure difference | $\Delta p$ | Pa |
| Probability | p | — |
| Temperature | T | °C or K |
| Temperature difference | $\Delta T$ | K |
| Velocity | v | m/s |
| Volume | V | $m^3$ |
| Width | W | m |

### Indices

| | |
|---|---|
| Air change rate | ach |
| Buoyancy | b |
| External | e |
| Infiltration | inf |
| Internal | i |
| Mechanically | mech |
| Occupant | occ |
| Open | open |
| Open window | ow |
| Reference | ref |
| Seasonal | seas |
| Total | tot |
| Ventilation | vent |
| Wind | w |
| 50 Pa test pressure | 50 |

## INTRODUCTION

### Behaviour and its Context

The action of airing and ventilating an internal space is, generally, neither a simple reflex action nor a rational well thought out act. Nevertheless, among individuals or even households, behaviour appears to be fairly consistent, indicating that a "subjective rationality" exists in behaviour. This implies that people normally try to act in a way which is defined as "as good as possible" by themselves.

In principle, the behaviour of people results predominantly from a learned social process, influenced by factors such as standards, values, attitudes and expectations. However, practical considerations also cause behavioural variations among households. People act within a framework of restrictions, including social factors (phase and size of household), physiological factors (age, sex, health), the availability of resources (money, knowledge, time), the quality of the dwelling (airtightness) and the availability of facilities to control the microclimate within the dwelling (windows, ventilation and heating systems). This study is thus confronted with the conflicts between inhabitants requirements, housing microclimate and available means of action.

### Behaviour Systems

In view of these factors, it is not surprising that a large variation in behaviour is found among households. However, groups of individual households displaying similar types of behaviour can be discerned fairly well. This makes it possible to generalise patterns of behaviour and, if necessary, to try and change particular behavioural aspects, for instance the way occupants ventilate or air their dwellings. The scheme illustrated in Figure 1 shows such a behavioural model. Central to this scheme is the actual behaviour of occupants of dwellings with respect to airing and ventilation, known as "HOW". Chapter 1 of this report refers to this block and is concerned with how people behave. As such, information on "HOW" people behave is meaningless without some insight into the reasons "WHY" they behave as they say, do, or intend to do. The scheme in Figure 1 shows the main clusters of variables explaining behaviour and Chapter 2 relates these variables to actual behaviour. It can be assumed that behavioural intentions and actual behaviour are strongly related to the sensory perception of comfort with respect to the micro-climate in dwellings. In other words, perceived thermal comfort can be viewed as one of the main reasons for airing or ventilating dwellings or rooms.

The use of windows affects ventilation rates in dwellings and consequently influences the amount of energy required for heating. Chapter 3 uses the ventilation patterns described in Chapter 1 to estimate ventilation rates due to window opening and the resulting energy consumption.

Chapter 4 considers the possibility of modifying ventilation behaviour either directly by means of information campaigns or indirectly by technical improvements to ventilation equipment or window design.

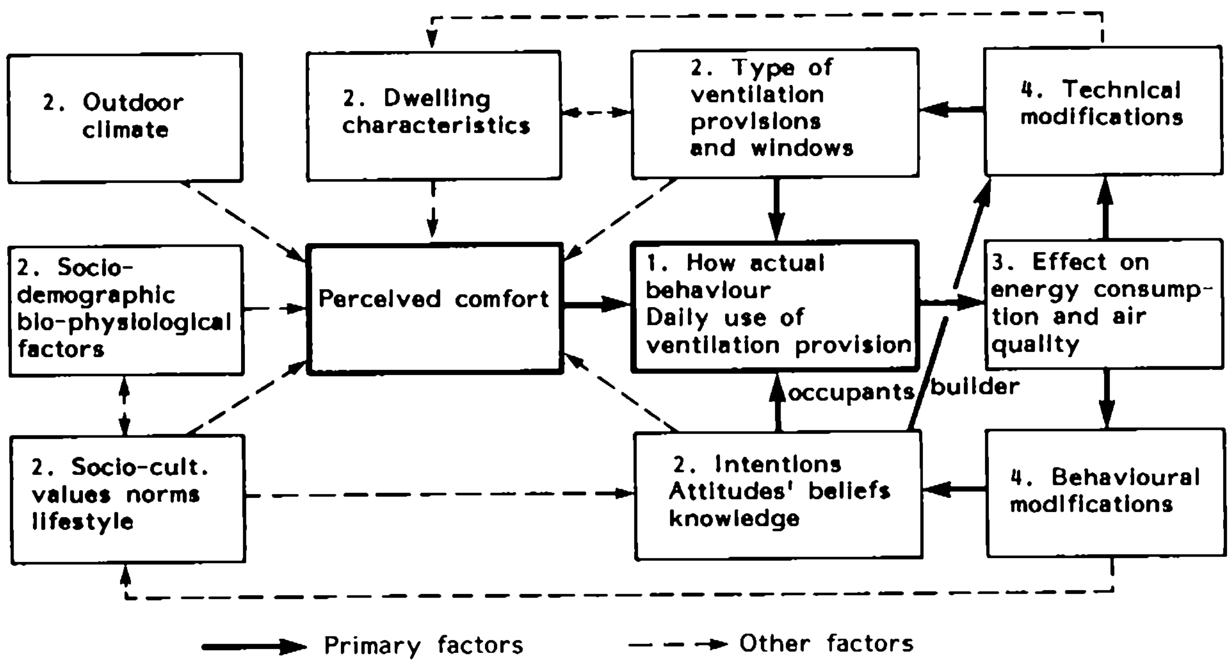



**Figure 1: Model of ventilation behaviour**

## Indoor Air Quality

Special attention should be paid to indoor air quality since it is an important factor influencing the micro-climate experienced in dwellings. The increasing awarenesss that indoor air quality aspects may restrict energy conservation by infiltration and ventilation measures has led to extensive investigations of different ventilation strategies. In order to reduce energy consumption, air infiltration and ventilation rates have to be minimized, but to maintain healthy, safe and comfortable conditions for the inhabitants and to avoid damage to the building fabric, an adequate supply of outdoor air should be maintained. Within the framework of the IEA Programme on Energy Conservation in Buildings, Annex IX, a report has been published on this subject [4].

There are three main reasons for ventilating buildings and dwellings:

- to avoid damage to the building fabric from pollutants such as moisture;
- to decrease annoyance to the inhabitants from odours;
- to minimize health risks from tobacco smoke, radon, mites and other allergens, organic vapours and gases, formaldehyde etc.

## Ventilation Systems and Strategies

Ventilation is the purpose provided flow-rate of air through a building by which outdoor (fresh) air enters and indoor (stale, polluted) air leaves. Ventilation should be distinguished from infiltration which is the unintentional entry of outdoor air through gaps, cracks and other imperfections in the building envelope.

There are two main types of ventilation system

- natural ventilation : through windows, grilles, ducts and other such devices.
- mechanical ventilation : by central or decentral fan systems for exhaust, or for both supply and exhaust. Ventilation is, in some cases, combined with air treatment facilities such as heating, heat recovery and filtration.

Ventilating is defined as providing an essentially continuous rate of fresh air by operating purpose-provided openings or mechanical ventilators.

Airing is defined as the opening of windows or doors wide during a limited period of the day in order to change the air or restore its quality.

From the viewpoint of energy conservation the air change rate should be as low as possible. However, to maintain indoor air quality, ventilation rates must be sufficient to avoid unacceptably high pollution levels. The balance achieved between these conflicting requirements is largely influenced by the behaviour of the building inhabitants.

# CHAPTER 1: How do People Behave?

## Introduction

Three methods were used to assess the actual behaviour of inhabitants. These were:

- survey techniques (interviews, postal questionnaires)
- self-observation (diaries, log books)
- direct measurements (independent observations of open windows, photography, use of microswitches)

The advantages and reliability of these methods are described later in section 1.6.

Each participating country undertook several projects concerned with inhabitants behaviour with respect to ventilation. Table 1.1 shows the size of the sample and the data collection methods used in each of these projects.

| Country | Projects | Sample Size | Questionnaires/ Interviews | Log Books | Obser-vations | Photo-graphy | Micro Switches | Ref. |
|---|---|---|---|---|---|---|---|---|
| Germany | Berlin | 9 | x | x | | | x | 21 |
| | Duisburg | 24 | | | x | x | | 17 |
| | Worms | 230 | x | x | x | | | 5 |
| The Netherlands | Almere | 50 | x | | | | | 50 |
| | Huizen | 31 | x | | | | | 51 |
| | Oosterhout | 36 | x | x | | | | 52, 53, 39 |
| | Schiedam | 80 | x | x | | | x | 54, 55 |
| | Zwolle | 104 | x | | | | | 56 |
| | NWR (National survey) | 1500 | x | | | | | 9 |
| | NWR (12 estates) | 600 | x | | | | | 10 |
| Switzerland | EMPA/BUS | 32 | x | | x | | | 42 |
| | Limmatstrasse | 254 | x | | | x | | 38 |
| | La Chaumière | 24 | x | | | | x | 43, 20, 12 |
| | Maugwil/Marty | 60 | x | | | | | 73 |
| United Kingdom | BRE (dwellings) | 236 | x | | | | | 33 |
| | BRE (office buildings) | 5 | x | | | x | | 27 |
| | Brundrett's study | | x | | | | | 13 |
| | Cambridge | 8 | x | x | x | | | — |
| | Dale's inquiry | 230 | x | | | | | 15 |
| | Surrey University | Int.:140 Postal q. 301 | x | | | | | 16 |
| Belgium | National enquiry (Namur Univ.) | 3000 | x | | | | | 7 |
| | Namur | 40 | x | x | x | | | 7 |
| | S.N.L. (BBRI) | 2400 | x | | | | | 6 |

**Table 1.1: Summary of projects and measurement methods**

The window use results in this report are, as far as possible, expressed as the number of open windows per dwelling $N_{OW}$. However, where it is not possible to use the $N_{OW}$ value, results are given as a percentage of hours per day. $N_{OW}$ is calculated using the formula:

$$N_{ow} = \frac{\sum_{t=0}^{T} N.t}{T} \text{ (per dwelling)} \tag{1.1}$$

where N = the number of windows that are open
t = the duration of opening of each window
T = the period of observation

$N_{OW}$ can be regarded as the mean value of the actual number of windows open per dwelling if that dwelling was examined continuously during the period concerned. For example, if $N_{OW} = 1.5$ for a 24h period the actual window behaviour could have been either:

1. one window open for 24 hours and a second window open for 12 hours (ie. $(24 + 12)/24 = 1.5$);

2. ten windows open for 3.6 hours (ie. $(10 \times 3.6)/24 = 1.5$).

These examples indicate only the extreme combinations.
The advantages of the $N_{OW}$ number are:

- values for different rooms in a dwelling can be added to produce either a whole dwelling value or a value for a group such as all bedrooms;

- the value is independent of the total number of windows in the dwelling;

- it may be defined for different periods such as morning, month etc.

### 1.1 Window Use Throughout the Year

In this section the results of three projects are considered, these being Duisberg (Germany)[17], Schiedam (Netherlands)[54] and SLC (UK)[18]. Figures 1.1, 1.2 and 1.3 show the mean number of open windows ($N_{OW}$) per dwelling for each month of the year. The different projects show different $N_{OW}$ values for corresponding months but the pattern over the year is similar.

#### 1.1.1 Range of $N_{OW}$ Values

$N_{OW}$ has a minimum value in January or February and a maximum in July or August. The ratio of the minimum and maximum values for each project are SLC 1:7, Duisberg 1:4 and Schiedam 1:2.5, while the corresponding minimum $N_{OW}$ values are 0.25, 0.3 and 1.5 respectively. Some of these differences can be accounted for by the presence of mechanical exhaust ventilation systems. In each case the living rooms showed a large variation in $N_{OW}$ value while the bedrooms had a more constant value. Discomfort due to draughts may account for the large variation in living rooms, whereas in bedrooms, particularly when no one is present, draughts have less influence and the need for fresh air is more or less constant throughout the year.

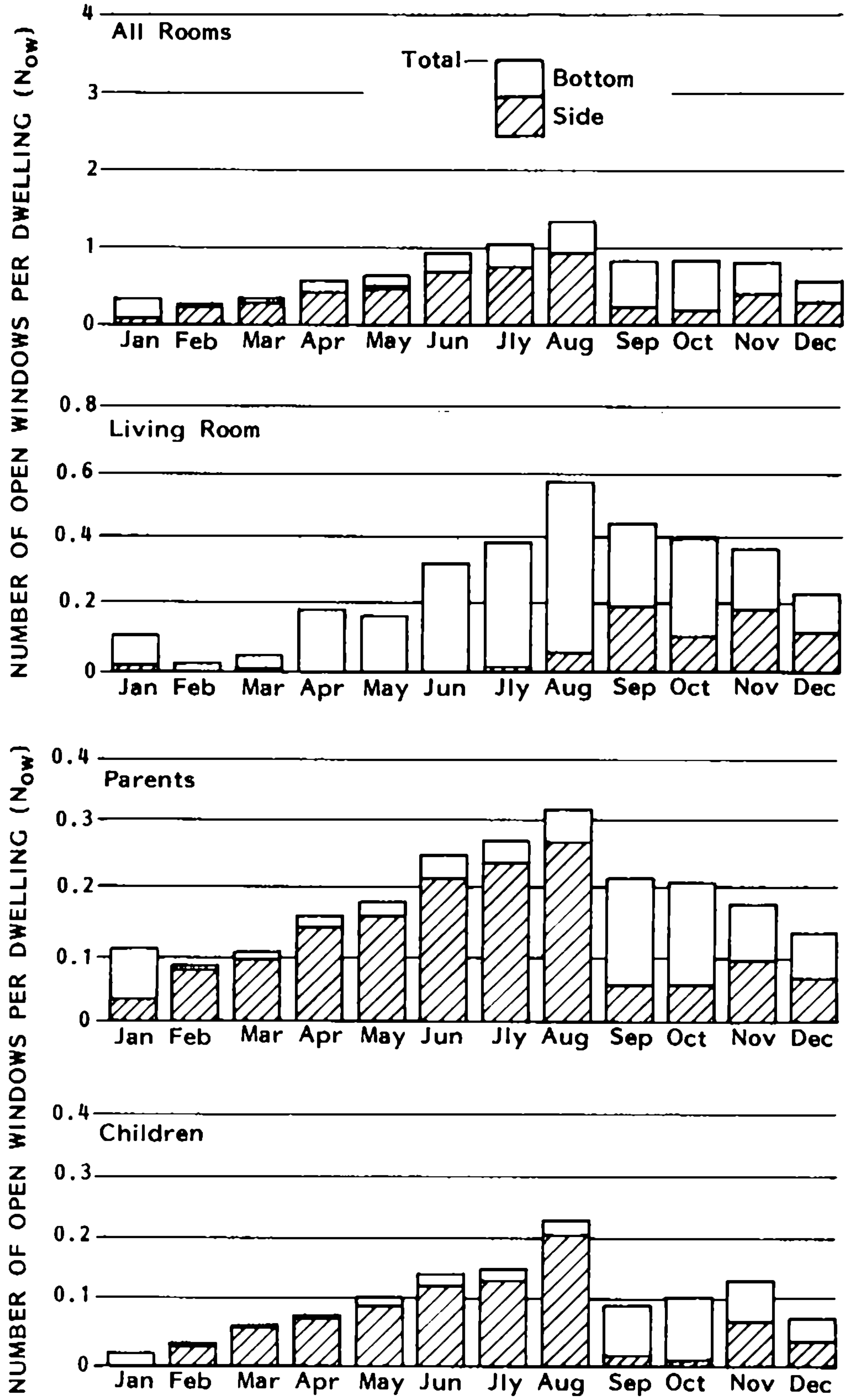



**Figure 1.1: Number of open windows per dwelling (Duisburg project)**

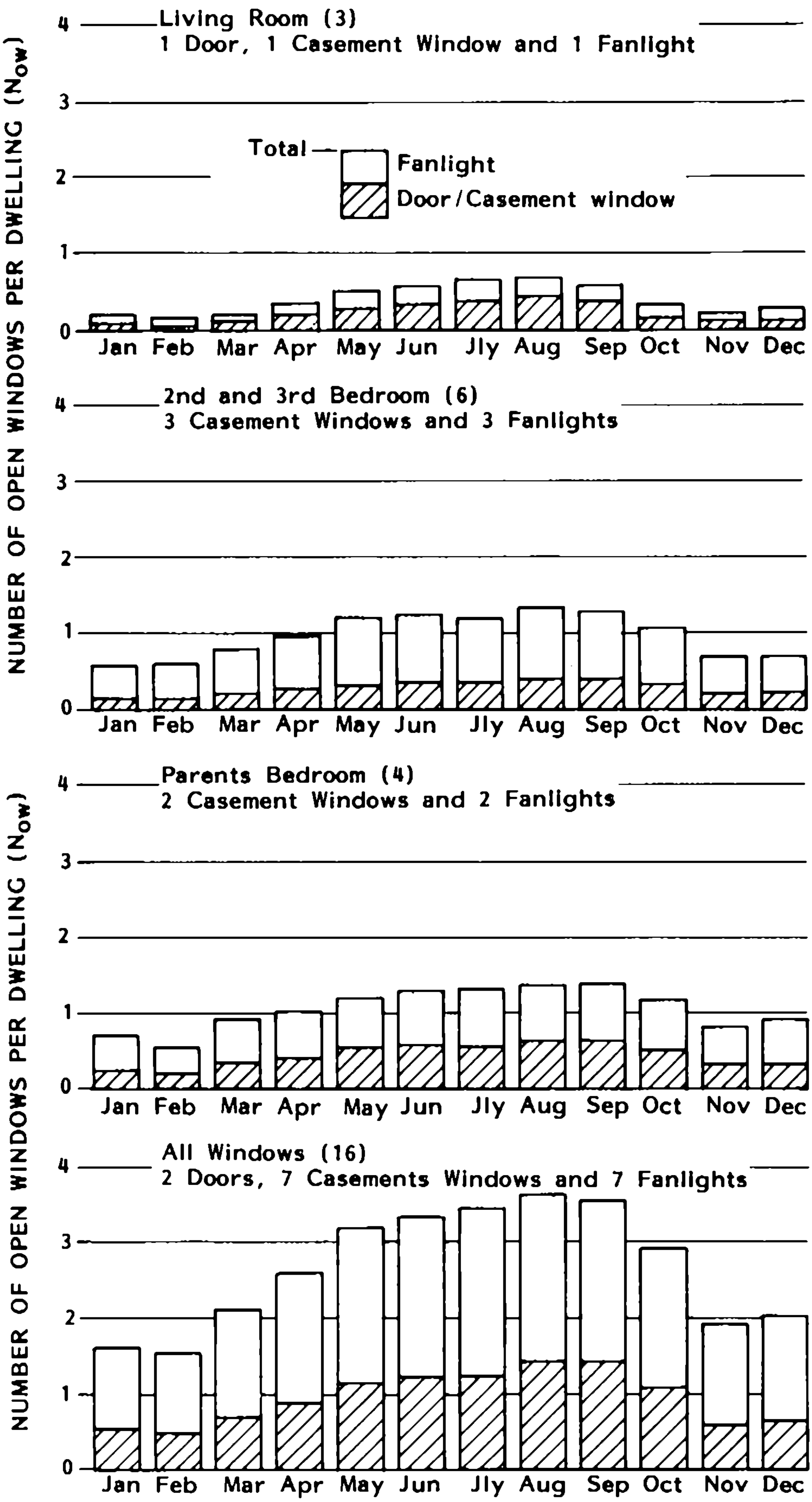



**Figure 1.2: Number of open windows per dwelling (Schiedam project)**

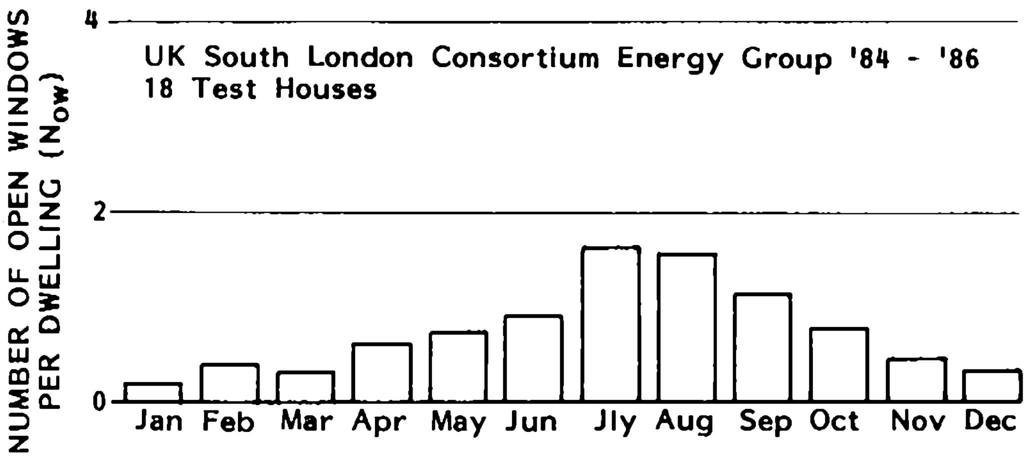



**Figure 1.3: Number of open windows per dwelling (SLC project)**

### 1.1.2 Effect of Window Types

The use of fanlights, side hung casement windows and tilting windows were studied in the Duisberg and Schiedam projects. In the Duisberg project, occupants showed a preference for wide window opening in the first half of the year and for smaller tilt positions during the remainder of the year. Both types of window use showed a wide variance over the months. In the Schiedam project, fanlights were used more than casement windows, especially in the bedrooms. The use of fanlights was found to be slightly more constant throughout the year than that of casement windows.

## 1.2 Number of Open Windows

Table 1.2 shows the use of windows according to type of room for dwellings with different ventilation systems. Figures in this table are based on mean Winter conditions of an external temperature of 5°C and a windspeed of 3.5 m/s.

In naturally ventilated dwellings, two groups of conditions could be discerned for the daily use of windows; these were:

- $N_{OW} = 0.37$ (ie 9 hours per day) for the Belgian, Swiss La Chaumiere and UK Surrey University projects;

- $N_{OW} > 1$ (ie at least one window open all the time) for the Dutch Schiedam and Almere RAD, the Swiss EMPA/BUS and the German Worms projects.

In dwellings with mechanical exhaust ventilation and, in some cases, mechanical supply (air heating systems), window use appeared to fall between the above two groups, with a mean $N_{OW}$ value of 0.61 (ie 14.6 hours per day).

Table 1.3 shows the relationship between the type of window or ventilator and its use for Winter conditions of 5°C outside temperature and 3.5 m/s wind speed.

| | Sum Total per Dwelling | | | Living Room | | | Kitchen Apart | | Bath-Room | Mean Bedroom | | Sum Total Bedrooms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | no mech. vent. | mech. exhaust | mech. supply + exhaust | no or only short mech. ventilation | mech. exhaust | mech. supply + exhaust | no mech. vent. | mech. exhaust (+ supply) | | no mech. vent. | mech. supply + exhaust | no mech. vent. | mech. supply + exhaust | mean number of bedrooms |
| | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | $N_{ow}$ | |
| La Chaumière | 0.32 | — | — | 0.02 | — | — | 0.04 | — | — | 0.26 | — | 0.26 | — | 1 |
| Empa/Bus | 1.66 | — | — | 0.37 | — | — | 0.10 | — | — | 0.60 | — | 1.19 | — | 2 |
| Worms older (5) | 1.54 | — | — | 0.08 | — | — | 0.04 | — | 0.23 | 0.40 | — | 1.21 | — | 3 |
| Worms new (6) | 1.58 | — | 1.16 | 0.22 | 0.10 | 0.17 | 0.17 | 0.13 | — | 0.60 | 0.45 | 1.19 | 0.09 | 2 |
| Namur 40 | 0.42 | — | — | 0.04 | — | — | 0.04 | — | 0.04 | 0.15 | — | 0.30 | — | |
| Namur 3000 | 0.31 | — | — | 0.04 | — | — | 0.05 | — | 0.04 | 0.09 | — | 0.18 | — | |
| Belgium BBRI | 0.45 | — | — | 0.02 | — | — | 0.05 | — | — | 0.13 | — | 0.38 | — | |
| Schiedam | 2.05 | — | — | 0.12 (+0.09) (2) | — | — | 0.03 (+0.18) (2) | — | — | 0.18 (+0.36) (2) | — | 0.54 (+1.09) (2) | — | 3 |
| Almere | 1.15 | — | 0.39 | 0.11 (+0.08) (2) | — | 0.11 (+0.04) (2) | — | =liv.room | — | 0.24 | 0.06 | 0.96 | 0.24 | 4 |
| Huizen | — | 0.44 (7) | — | — | 0.02 (+1.12) (3) | — | — | =liv.room | — | 0.14 | — | 0.42 | — | 3 |
| Oosterhout | 0.[illegible] (7) | — | — | 0.02 (+0.30) (3) | — | — | 0.03 (+0.28) (2) | — | 0.08 | 0.25 | — | 0.75 | — | 3 |
| Zwolle RAD | — | 0.61 (7) | — | — | 0.03 (+1.02) (3) | — | — | =liv.room | — | 0.29 | — | 0.58 | — | 2 |
| Zwolle AIR | — | — | 0.44 | — | — | 0.02 | — | =liv.room | — | — | 0.21 | — | 0.42 | 2 |
| Univ. of Surrey | 0.56 | — | — | 0.02 | — | — | 0.03 | — | 0.06 | 0.27 | — | 0.44 | — | 2 |
| Mean $N_{ow}$ (1) | 0.99 | 0.525 | 0.66 | 0.095 (+0.23) | 0.05 (+1.07) | 0.1 (+0.4) | 0.06 (+0.23) | 0.13 | 0.091 | 0.28 (+0.36) (8) | 0.24 | 0.6 (+1.09) | 0.25 | |
| Mean hours | 83.7 | 12.6 | 15.9 | 2.27 | 1.2 | 2.4 | 1.39 | 3.12 | 2.18 | 8.65 (8) | 5.76 | 15.5 | 6 | |

**Notes**

(1) arithmetic mean

(2) fanlights

(3) ventilation grille

(4) Oosterhout excluded

(5) relatively poor airtightness, no mech. ventilation (ducts only)

(6) three types of ventilation applied: mech. + heat recovery; mech. exhaust; no mech. ventilation (ducts only)

(7) ventilation grille excluded

(8) ratio between main bedroom, childrens bedroom and bedrooms not used to sleep is 6 : 3 : 2 (approximately)

**Table 1.2: Window use according to room type and ventilation system**

| window type | area of opening | hours/day | $N_{ow}$ |
|---|---|---|---|
| ventilation grille opened | 50 cm² | 10 | .42 |
| fanlight | 0.1 m² | 7 | .29 |
| casement window or balcony/garden door | 0.5 m² | 3 | .13 |
| front door | 1.6 m² | .1 | .004 |

**Table 1.3: Use of windows according to type**

## 1.3 Variation by Type of Room

The house may be divided into three distinct zones, these being "lived in", "functional" and "sleeping". It is suggested that each has its own ventilation behaviour. The assignment of a room can vary from household to household, and may also vary somewhat during the day. The living-room is the basic "lived in" room, while others, such as the kitchen and the bathroom, are the main "functional" rooms for the households studied. A bedroom may be a "lived in" room for much of the day but it must be noted that bedrooms used only for sleeping were considered in this study.

From the data collected, it appears that occupants exhibit different ventilation behaviour in each of these zones. Table 1.4 shows the type of room in rank order of window use for each of the dwellings investigated. These results may be summarised as follows:

- the main ventilation zones are the bedrooms;
- the greatest percentage of windows which are never opened are in living rooms;
- a similar mean percentage of open windows was found in kitchens and bathrooms. This was of the same order as that for the living rooms even though kitchens and bathrooms are subjected to vapour production.

## 1.4 Variation with Time of Day

The investigations have shown characteristic daily patterns for different types of room. This may indicate that habit factors influence window and door opening as well as motivational factors such as outside temperature, wind velocity etc.

Typically, maximum window opening occurs in the morning (see figure 1.4). During cooking, in the early afternoon, the number of open windows is still relatively high but it gradually decreases during the afternoon. At about 5pm another peak can be observed which is probably correlated to the return home of working inhabitants. Window opening decreases again during the evening and remains fairly constant during the night.

| Project / Rank Order | La Chaumière (CH) | Empa/ Bus (CH) | Worms (D) | Namur (n=40) (B) | Namur (n=3000) (B) | B.B.R.I. (B) | Schiedam (NL) | Surrey (UK) |
|---|---|---|---|---|---|---|---|---|
| 1 | Parents bed. + 2nd bed. (0.26) | Parents bed. (0.66) | Parents bed. (0.58) | Parents bed. (0.193) | Parents bed. (0.109) | Mean bedroom (.13) | Parents bed. (1.3) | Mean bedroom (.27) |
| 2 | Kitchen (0.04) | 2nd bedroom (0.53) | Small bedroom (0.42) | 2nd bedroom (0.106) | 2nd bedroom (0.074) | Kitchen (.05) | 2nd bedroom (0.63) | Kitchen (.03) |
| 3 | Living (0.02) | Living (0.37) | 2nd bed. (0.35) | Kitchen (0.43) | Kitchen (0.46) | Living (.02) | Small bed. (0.51) | Living (.02) |
| 4 | — | Kitchen (0.1) | Living (0.13) | Bathroom (0.039) | Bathroom (0.038) | | Kitchen (0.38) | |
| 5 | — | | Kitchen (0.10) | Living (0.035) | Living (0.028) | | Living (0.29) | |

N.B. Values in brackets are the number of open windows per dwelling ($N_{ow}$)

**Table 1.4: Rank order of window use per type of room**

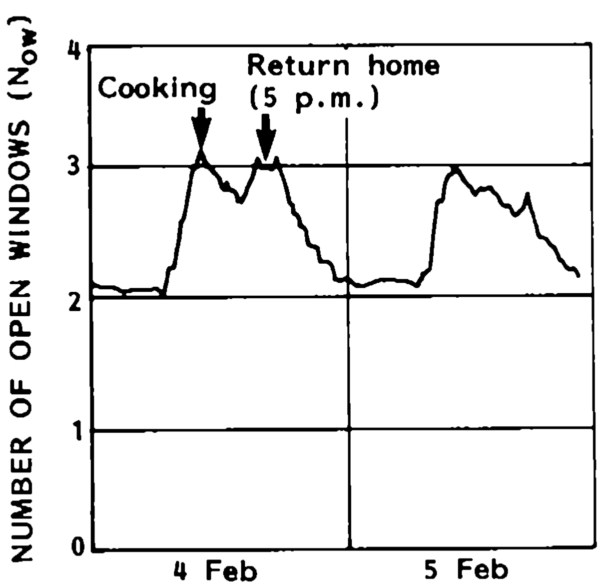



**Figure 1.4: Average winter days (Schiedam project) (Total of 1280 windows and doors)**

Figure 1.5 shows the 24 hour patterns for different types of room. In the bedroom, window opening is greatest during the night and least during the day, with a peak in the morning. The rather flat curve of window opening for living rooms could be explained by multiple short openings during the day. Several window opening maxima occur during the day for kitchens and these are quite well correlated with cooking periods.

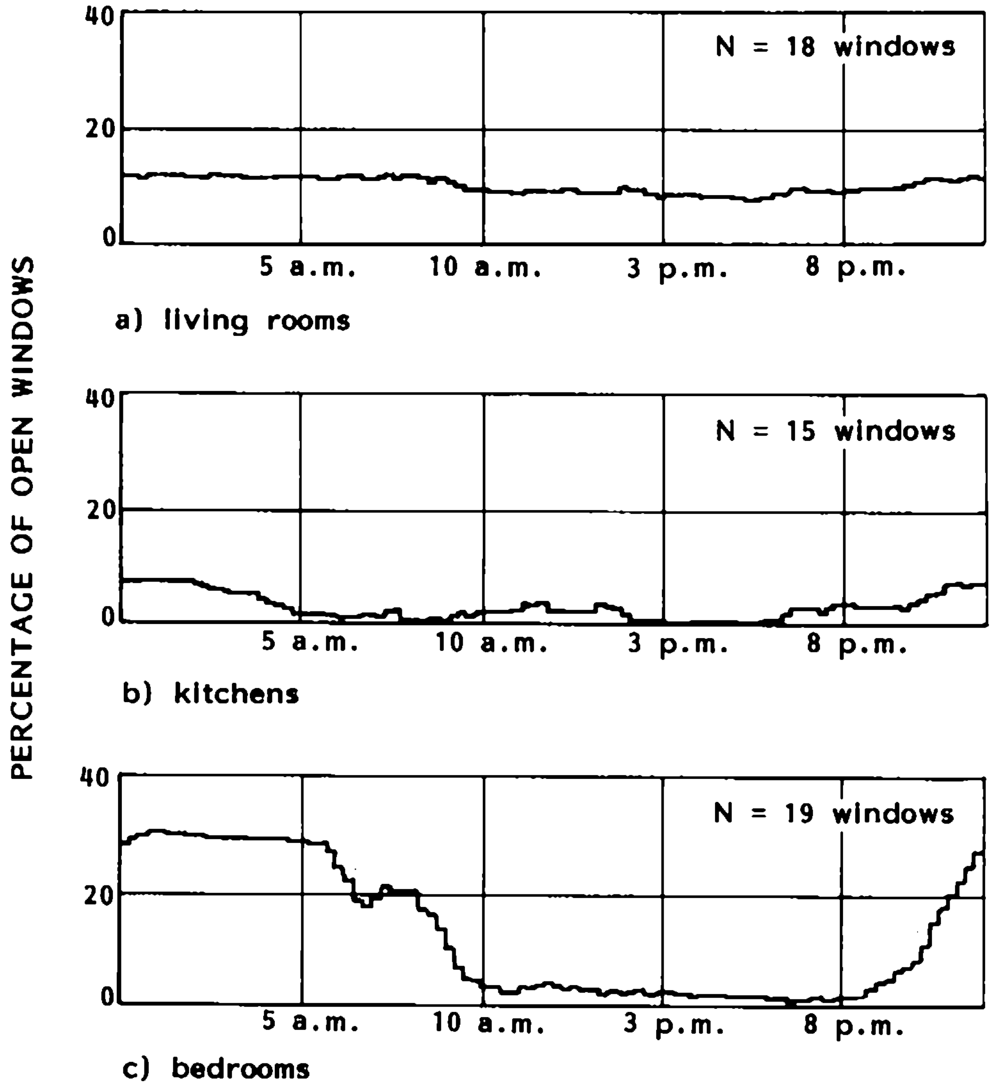



**Figure 1.5: Daily profiles of window opening (La Chaumière project)**

The number of windows which are open at different periods of the day in the bedroom and living room are summarized in Table 1.5. The maximum values for the bedrooms are probably due to the morning peak. Although the values differ markedly from project to project, the underlying trend is the same. The low values in the Swiss La Chaumiere and EMPA/BUS projects may be caused by differences in window design or building construction. In living rooms, a lower and more constant window use is shown. With the exception of the La Chaumiere and Surrey projects, the results from the different projects are in good agreement.

However, this habitual behaviour is influenced by external factors. On colder or more windy days window opening decreases although even on cold and windy days some windows remain open.

| Period | La Chaumière | Empa/Bus | Worms (1) | Schiedam | Surrey |
|---|---|---|---|---|---|
| 0:00 – 8:00 | 0.43 | 0.83 | 1 | 0.5 | 0.15 |
| 8:00 – 18:00 | 0.16 | 0.57 | 2.5 | 2.3 | 0.21 |
| 18:00 – 24:00 | 0.23 | 0.60 | 0.5 | 0.7 | 0.38 |

(a) Parents bedroom

| Period | La Chaumière | Empa/Bus | Worms (1) | Schiedam | Surrey |
|---|---|---|---|---|---|
| 0:00 – 8:00 | 0.06 | 0.5 | 0.5 | 0.4 | 0.03 |
| 8:00 – 18:00 | 0.01 | 0.21 | 0.2 | 0.27 | 0.02 |
| 18:00 – 24:00 | 0 | 0.43 | 0.2 | 0.1 | 0.01 |

(b) Living room

(1) Mechanical supply + exhaust

**Table 1.5: Number of windows open for different periods throughout the day ($N_{ow}$)**

## 1.5 Degree of Opening of Windows and Doors

In its simplest form, the micro-switch technique does not give any indication of how wide a window (or door) is open. However, such information can be obtained from direct observations of windows, log book entries, and the answers to questions on degree of opening in questionnaires.

In the various projects three levels of opening (i.e. closed, slightly open and wide open) were examined. Large variations among the opening levels were found. In the Almere, Oosterhout, Huizen and Schiedam projects, the Dutch team observed a tendency towards a larger percentage of wide open windows. The Belgian team's findings, based on interviews with the occupants in 2400 social houses, showed a trend towards slightly open windows. The Swiss team found a majority of closed windows in the two apartment buildings at EMPA/BUS. These findings were true for practically every type of room.

When the use of different types of ventilators was studied, it was found that grilles tended to be left open most, followed by fanlights and then casement windows. As might be expected, balcony doors were open for much longer periods than front doors.

The Dutch team observed a greater percentage of opened windows in the bedrooms and living rooms of 20 year old apartments (Schiedam) than in newly built one-family dwellings (Almere, Zwolle and Huizen).

The weather also influences the degree of opening of windows. In the Schiedam flats fanlights were left open for more than eight hours in 17% and 8% of living rooms when the outside temperature was 5°C and -8°C respectively. In the Swiss EMPA/BUS project an outside temperature change from 15°C to -5°C produced changes in the percentage of open or slightly open casement windows of from 41% to 34% in the mornings and from 32% to 24% in the afternoons. For the main bedrooms these figures are 70% to 64% and 55% to 44% respectively. These points are summarized in Tables 1.6 and 1.7 which show the results for living rooms from the Dutch and Swiss teams.

## 1.6 Reliability and Validity of Measurement Techniques

Three methods were used to measure the actual behaviour of inhabitants:

- survey techniques : postal questionnaires, verbal interviews;
- direct measurements : use of independent observers, photography, micro-switches;
- self observations : use of diaries or log books.

Survey techniques were used in all the projects since this method of data collection provides a great deal of information. However, problems of reliability arise because people tend to give answers relating only to the two or three weeks before the interview and they also tend to modify their replies according to how they think they should behave. Reporting to an interviewer seems to provide more accurate data than filling in a questionnaire since people check the actual situation and report all openings rather than just wide open windows.

A method of assessing the reliability of the survey results was to observe the fronts of the houses. The observations were performed by an observer walking around a number of buildings during the day and either noting the number of open windows on each facade or photographing the open windows at different times. The observation method is very flexible; it can be used either for numerous observations of a small number of buildings or for observations of a large number of buildings on

| | < 0°C | | > 5°C | |
|---|---|---|---|---|
| | % ajar | % wider | % ajar | % wider |
| < 1/2 hour | 10 | 17 | 10 | 13 |
| 1/2 – 1 | 4 | 15 | 6 | 22 |
| 1 – 2 | 1 | 4 | — | 6 |
| 2 – 4 | — | 3 | 1 | 11 |
| 4 – 8 | — | 1 | 1 | 6 |
| > 8 h | — | 1 | 3 | 4 |
| Total | 16 | 43 | 21 | 62 |

**Table 1.6: The way windows (or balcony door) are opened in the living-rooms (Schiedam)**

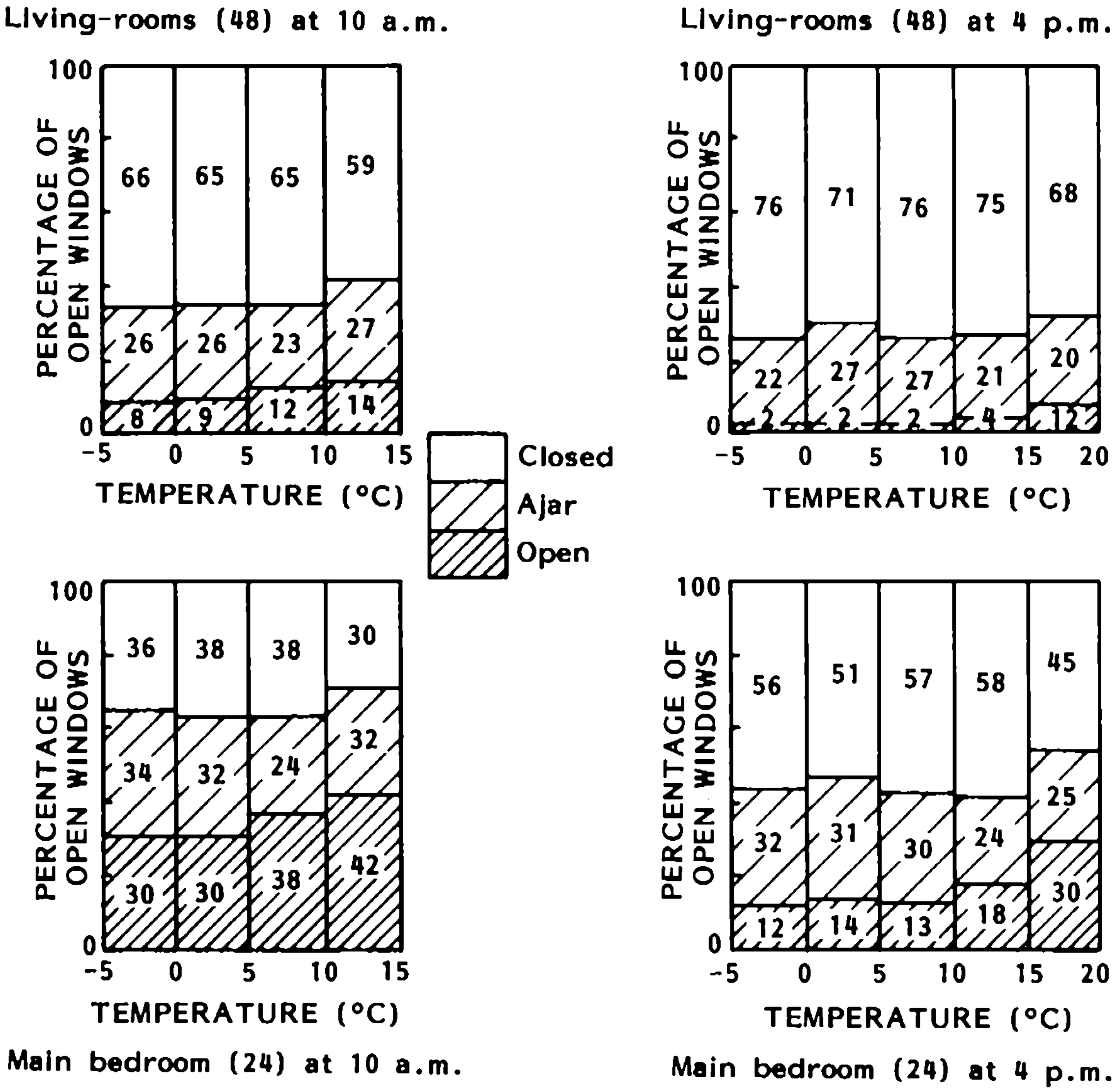



**Table 1.7: Relationship between window opening and outside temperature. (65 observations per block) (EMPA/BUS)**

a limited number of occasions. This method also has the advantages of being cheap and easy to carry out for short term measurements and of not influencing the behaviour of inhabitants. However there are some drawbacks, for example the duration of window opening is unknown, not all types of dwelling can be observed since some windows cannot be seen by the observer, no observations are possible at night, and the method is time consuming if many observations are to be made.

Another way of monitoring window opening behaviour is to use switches or micro-switches fixed to the window frames (see Figure 1.6). In theory there is no feedbaack on behaviour and it is a very accurate method. Apart from the few weeks following the installation of the switches, direct measurements give a very detailed picture of when and for how long the residents' windows are open. However, in general, the micro-switch technique does not give any information about the size of the openings. It is also very expensive and is not always accepted by the inhabitants.

While the observations to determine how people behave were being performed, a very detailed questionnaire was given to the inhabitants to ascertain how they said they behave and why. By comparing the observed and admitted behaviour, the reliability of what people say, with regard to ventilation , can be inferred. It appears that there is little difference between what people say they do and what they actually do. For example, from the Schiedam project results, it appeared that the correlation between what the inhabitants say and what they do was very high. During the winter of 1985, a correlation on an individual level (i.e. per apartment) of 0.9 was found when windows or fanlights were opened on average for more than one hour per day. Similarly, for windows or fanlights which were opened for less than one hour per day, the correlation was 0.73. It should be noted that there was also good correlation for the following year.

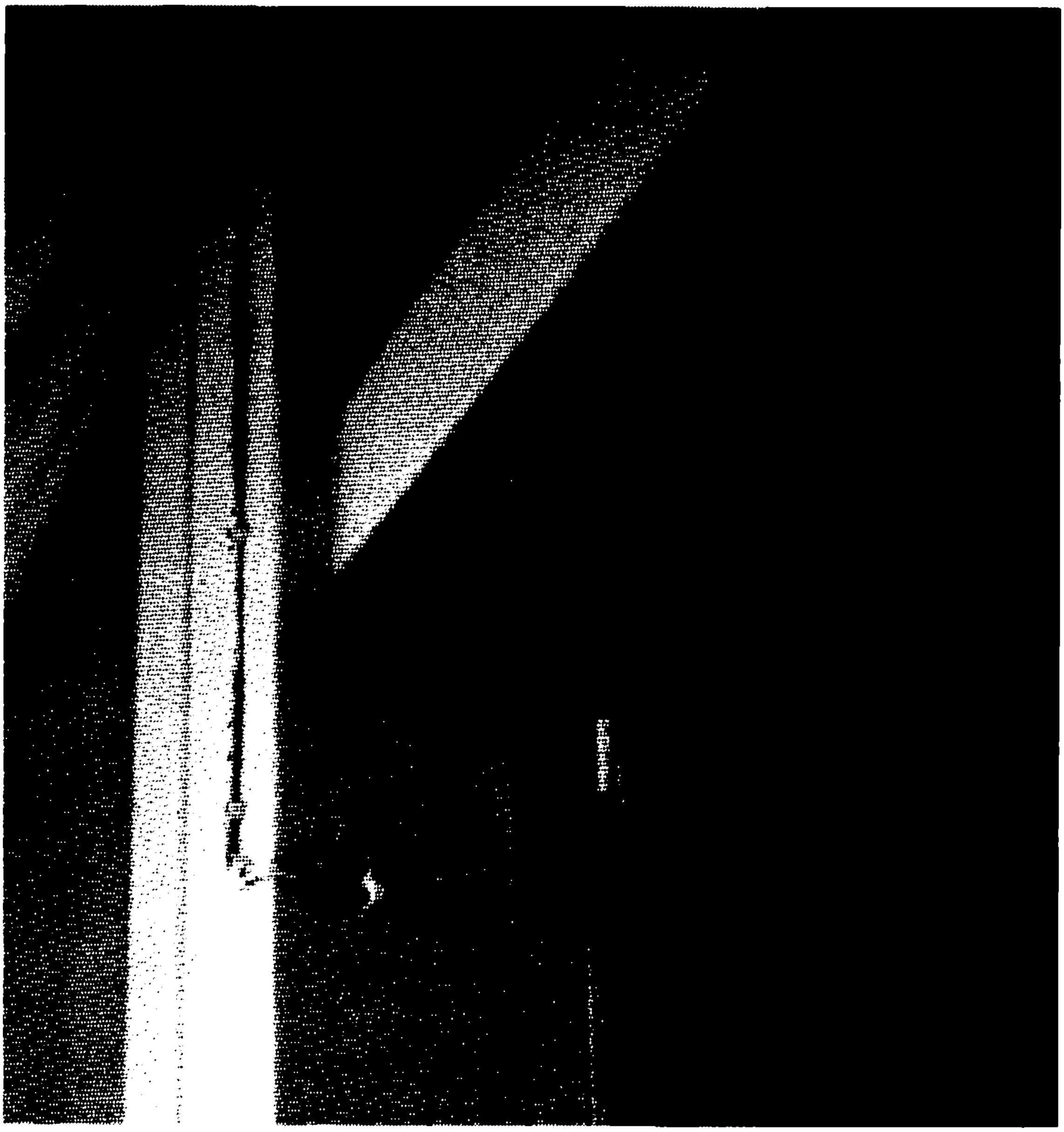


**Figure 1.6 Magnet and reed relay switch installed on an apartment window in Schiedam**

## CHAPTER 2: Why? - Motivation for Occupant Behaviour

It can be assumed that behavioural intentions and actual behaviour are strongly related to the sensory perception of comfort with respect to the micro-climate in dwellings. Thermal comfort is assumed to be predominantly determined by air temperature, radiant temperature, relative humidity, clothing and physical activity (metabolism)[3]. Other factors influencing the experience of micro-climate in dwellings include:

- temporal — biorythmic patterns during the day, season of the year, day of the week, previous thermal experience of the inhabitants;
- spatial — room characteristics (eg volume, contact with the outside, lighting level, chromatism, furniture type, position and type of windows and doors);
- environmental — perceived indoor air quality, accoustic and odour characteristics, occupancy of the dwelling or room (number and characteristics of people), appropriation of dwelling or room, freedom to control the micro-climate;
- human — general sense of well being; socio-cultural factors,
- external — level of technical development, outdoor climate.

It should be noted that many of these variables interact with each other, often in a synergetic way.

In this chapter, correlations between window use and a number of factors affecting the experience of the micro-climate are investigated. However, it should be noted that if no correlation is found, it does not necessarily mean that no correlation exists.

### 2.1 Dwelling Fabric Factors

Dwelling fabric factors cover variations in the design of dwellings and in the heating and ventilation systems installed. In general, differences in these factors appear to affect window opening rates by differentially influencing the occupants' need to ventilate and the ease of window opening. In this section, the relationships between dwelling fabric factors and window opening during the Winter are considered.

#### 2.1.1 Type of Dwelling

The Belgian study has shown that the type of dwelling (house vs apartment) influences the length of time windows are open. However, the direction of the effect depends on the type of room being considered. In houses, as compared to apartments, windows in living rooms and kitchens were found, on average, to be open for shorter periods, whereas windows in bedrooms were open for longer. Dutch research showed that in apartments, living room windows were opened less but internal doors were more likely to be left open. This could be interpreted as a compensating behaviour. Belgian research has also shown that dwelling type has an effect on how wide windows are left open. In apartments, windows, if opened at all, are more likely to be slightly open as opposed to wide open, whereas the opposite is the case in houses. This effect holds for both winter and summer.

### 2.1.2 Orientation of Rooms

Both Dutch and UK research has shown that the orientation of particular rooms affects window opening. The Dutch team found that, when the sun was shining, south-facing living rooms and bedrooms were more likely to be ventilated for longer periods than similar rooms orientated in other directions. The UK team produced results which suggest a similar effect. Their research showed that, during Spring, there was a small but statistically significant correlation between the frequency of window opening in living rooms and the direction the windows faced (ie whether they were south-facing). These data suggest that the relationship between room orientation and window opening is mediated by a solar gain effect.

### 2.1.3 Window Design

The design of a window, with regard to how it is hung in its frame and the direction of travel of the opening part, influences window opening. Belgian research has shown that bottom hung windows which open inwards are opened more frequently than other types. This tendency is strongest in living rooms and kitchens. The Dutch team found that fanlight windows are opened twice as frequently as side hung casement windows. Reasons for these differences in use could be that different designs offer different areas of opening and are therefore used for different purposes and that some designs are easier to open. In the Netherlands, where ventilation grilles were installed, they were predominantly left open. The dwellings concerned were all well insulated.

### 2.1.4 Age of Dwelling

The UK team found that the newer the house the higher was the proportion of rooms in which a window was opened on a daily basis during the Spring (April and May). The Belgian team, using pressurisation tests, found that older houses were less airtight and that the windows in less airtight dwellings also tended to be opened more. These conflicting results mean that the relationship between the age of a dwelling and the frequency of window opening remains uncertain. It is possible that the relationship between two or more intervening variables in the Belgian and UK data was different, for example the way in which the airtightness of a dwelling inter-relates with the occupants' subjective impression of its airtightness and their general tendency to ventilate.

### 2.1.5 Level of Insulation

The level of insulation found in a dwelling might be expected to influence window opening. The UK team found no association between the proportion of double glazed windows in a house and frequency of window opening. The Dutch team showed that the double glazed windows at bedroom level, in well insulated single family dwellings, were opened more than in identical single glazed and less insulated dwellings. However, the Dutch team was able to show that people living in single glazed dwellings were more likely to report removal of condensation on windows as a reason for opening them. The failure in the Belgian results, to date, to demonstrate any effects of double glazing on ventilation rates may be due to factors such as variations in the thermal mass of the dwellings, which were not taken into account by the researchers.

### 2.1.6 Space Heating and Mechanical Ventilation

Results showed that the type of space heating system installed in a dwelling affects window opening. The Belgian results indicated that windows in centrally heated dwellings were less likely to be opened for long periods than those in non centrally heated dwellings. This difference was most pronounced in bedrooms. The Dutch team found that dwellings with warm-air central heating were ventilated less than dwellings with radiator systems. This may be due to the fact that householders living in the former type of dwelling had been instructed not to open windows as this would upset the balance of the warm-air system. Research carried out in Germany examined the effect of the presence of a mechanical ventilation system in the dwelling. Window opening rates in dwellings in which various types of mechanical ventilation systems were installed were compared with those in dwellings without mechanical ventilation. Only small differences were found, but interviews with householders showed that they had little or no understanding of how to use their mechanical ventilation system. It may, therefore, be tentatively concluded that the presence of mechanical ventilation will only have an effect on window opening rates when its use is properly understood.

## 2.2 Lifestyle

Several characteristics of what can be called "lifestyle" are related to the use of windows, including the presence of occupants, smoking behaviour, activity level, attitude towards energy saving, indoor climate preferences and moisture production.

### 2.2.1 Presence of Occupants

From the Belgian study it could be concluded that the presence of occupants in the home and the use of windows were related: the longer the dwelling was occupied the more the windows, especially the bedroom windows, were kept open. However, the Dutch and UK studies showed that, in dwellings which were not occupied during the daytime, windows were used more often during the evening and night, so that over a 24 hour period there was little difference between dwellings which were occupied during the day and those which were not. During the parts of the day when the inhabitants were absent, those windows through which burglars could gain access were closed for security reasons.

### 2.2.2 Smoking Behaviour

Dutch and Belgian research, supported by the German results, showed a clear correlation between smoking behaviour and the airing and ventilation of living rooms. In the Netherlands it was found that, where occupants did smoke, the living room was ventilated, on average, for twice as long as in non-smoking households, even when mechanical ventilation systems had been installed. In Belgium an analysis of factors affecting window use in living rooms showed that smoke had the highest coefficient with window use. In answer to open questions on reasons for airing or ventilating the living room, replies such as "to freshen" and "to get rid of smoke" were often given. In newly built dwellings in the Netherlands, tobacco smoke was one of the indoor climate problems mentioned most.

2.2.3 Household Activities

The answers to open questions on reasons for window opening indicated that windows were opened in combination with house-keeping activities such as vacuum cleaning and airing bedclothes. In kitchens, window opening was related to cooking activities, cooking smells and vapour problems. Replies to open questions on why people close their windows showed that the "activities" of small children and pets also influenced window use. The daily course of opening windows appeared to be somewhat different at weekends. There were indications that, in some cases, differences between wives and husbands with respect to preferences in indoor climate or energy saving attitudes caused these modifications in window use. Also weekend parties influenced the use of windows and ventilation provisions.

2.2.4 Attitude to Energy Saving

A conclusion often found in the literature on energy saving is that the relationship between energy saving attitudes and beliefs and energy saving behaviour in practice is very weak. This finding appears to be confirmed with respect to window use. In the Belgian study, a relationship was found but energy saving attitude appeared to be only weakly correlated with window use. From the Swiss and German studies, it can be concluded that energy saving awareness influences the use of windows but the way in which this is carried out is not always energy-use efficient because of lack of insight into the physical characteristics concerned with ventilation and energy use. In most Dutch case studies questions about energy saving attitudes were not posed. However, where they were, no relationship was found with window use.

The way the heating energy bill was paid influenced the use of windows. In the German study, it was found that those who paid a "collective" bill, based on the mean energy use of the different apartments, kept the windows open more than those who paid a bill based on their own energy use.

2.2.5 Indoor Climate Preferences

Indoor climate preferences appeared to generate the highest correlation with the way windows and ventilation provisions were used.

The higher the preferred thermostat setting was, the less windows were opened. In all the countries participating in this study, it was found that the preferred temperature in the bedrooms was lower than in the living room. In the Netherlands, only a small proportion of the population preferred a bedroom temperature higher than 17°C. An important proportion of the windows in the main bedroom were kept open during the night even in cold winter conditions. Also, from the Dutch study, it appeared that preferences with respect to temperature were strongly related to clothing habits.

In Belgium and Germany, it was found that those who heated the whole dwelling ventilated least. In most Dutch studies, it was found that if people tended to ventilate or air their living rooms at a high level, they also tended to do the same in the bedrooms. The most frequently mentioned reason for opening bedroom windows was to get fresh air. This explains the fact that bedroom windows are opened for much longer periods than the windows of other rooms. The need for fresh air in bedrooms was also connected with health related beliefs and experiences such as headaches. Another reason for opening windows, which was often mentioned, was condensation.

The replies to open questions on why rooms, especially living rooms, were never, or very rarely, ventilated indicated that the need to maintain an adequate indoor climate (air quality) and problems with draughts were important factors. Other factors were found in Belgian and Swiss studies including protection against bad weather, safety, reduction of outside noise and pollution, and privacy.

German research showed that households which kept their radiator thermostats at a uniform temperature in all rooms opened their windows less than households which kept their radiator thermostats on different settings in different rooms. Interviews with the householders suggested that the difference in ventilation rate was related to differences in energy use awareness in the two types of household.

#### 2.2.6 Moisture Production

In the Belgian and Dutch studies a correlation was found between the use of showers (depending on the family size) and the use of the window in the bathroom. Dutch studies showed that where no openable windows had been installed in bathrooms, windows in the bedrooms were opened more, even when mechanical ventilation existed in the bathroom.

A relationship was also found between the frequency of using a washing machine and the use of windows. As has already been mentioned , kitchen window opening was strongly related to smell and vapour production.

### 2.3 Control Strategies

The way inhabitants use windows and how they react to external factors is complex and involves both the occupants and the heating and ventilating facilities available to them. In this section the reasons why people open and close their windows are considered so that ventilation strategies, ie. the way ventilation facilities are used, can be deduced.

#### 2.3.1 Reasons for Ventilating Reported by Occupants

Teams conducted enquiries and interviews in order to assess the reasons why people open or close their windows. in most cases inhabitants reported that they opened windows in order to:

- get fresh air in the bedrooms and living room;
- remove smells;
- remove stale air or condensation;
- air the dwelling during domestic activities.

Also of interest are the reasons for closing windows which include:

- to save energy;

- to prevent draughts;

- to maintain a preferred temperature level in the home;

- to protect the inhabitants from climatic conditions eg. cold and rain;

- to preserve privacy or safety;

- to reduce outside noise or pollution.

### 2.3.2 Strategies Inferred from Objective Recording and Self-Reported Data

The Swiss team has used observations of how people behave to explain the "act" of opening (or closing) windows according to the following motivations:

- domestic

- environmental

- social

- health and hygiene

- physiological and psychological

These opening categories apply well for large samples but they are not necessarily appropriate for smaller groups or individuals. However, the use of these categories allows opening (or closing) strategies to be defined.

The German team has structured opening strategies according to the duration of ventilation (from no opening at all to day long or night long opening) and the complexity of the ventilation pattern (ie. simple when it occurs regularly, complex if it is irregular, and variable when ventilation is simple in one room and complex in another). These two variables are independent of each other and represent two different aspects of ventilation behaviour.

In another type of strategy, the indoor temperature is controlled by leaving all the internal doors open while opening only one window or, conversely, by closing all the doors and obtaining thermal zoning by purposely operating windows and radiator valves.

Long-term experience (ie. "thermal history") may explain why some inhabitants tend to adopt an energy saving strategy while others do not, for example those disliking cold temperatures may open their windows without closing the corresponding radiators. The different geographical origins of inhabitants may also result in inadequate ventilation for the prevailing climatic conditions.

Assuming that an inhabitant wishes to follow a given strategy he may have difficulty in doing so because of the numerous obstacles he encounters. Such problems include:

- the window panes being blocked by plants, furniture, or small objects;

- the incorrect operation of windows or radiator valves;

- the open plan design of the dwelling, which does not allow the removal of smells;

- the high airtightness of the dwelling, which means that ventilation grilles must be left open, resulting in heat losses and draughts.

It can be concluded that individuals have their own coherent approach to regulating their comfort. They present a great variety of ventilation patterns but each pattern is consistent within its frame of reference, be it in the percentage of window opening or the duration of opening.

Another problem encountered by inhabitants is the confusing and often contradictory information given to them about their heating and ventilating systems. For example, inhabitants often have no idea about the function of their heating system with regard to the plant itself or the action of thermostatic valves.

## 2.4 Socio-economic Variables

An attempt was made to relate the size of the family to window use but no clear trend emerged. However the UK team analysed the influence of the density of people per house on opening duration and frequency by creating a variable representing the number of rooms per person for each household. The results obtained suggest that the more rooms per person in the household the less often windows were opened but those that were opened remained open for longer periods.

The behaviour of elderly people was found to be significantly different from that of younger people. It seems that the older people are, the less they ventilate.

It is perhaps surprising that socio-economic variables have not given more significant results and more research is needed into this aspect of ventilation behaviour.

## 2.5 Weather Factors

Of the motivational factors influencing inhabitants' window opening behaviour, weather conditions did show correlations which could be quantified more clearly than the others. Earlier findings by other researchers that window opening increases with increasing outdoor temperature and decreases with increasing wind velocity could not only be confirmed but also analyzed in more detail because of the large amount of data collected from the various projects in the participating countries. Unfortunately, there are still problems with the modelling and mathematical description of the different weather factors in a single relation.

### 2.5.1 Outdoor Temperature

Most of the investigations have shown that, in the temperature range -10°C to +25°C, a direct linear correlation between window use and temperature exists. An example is given in figure 2.1.

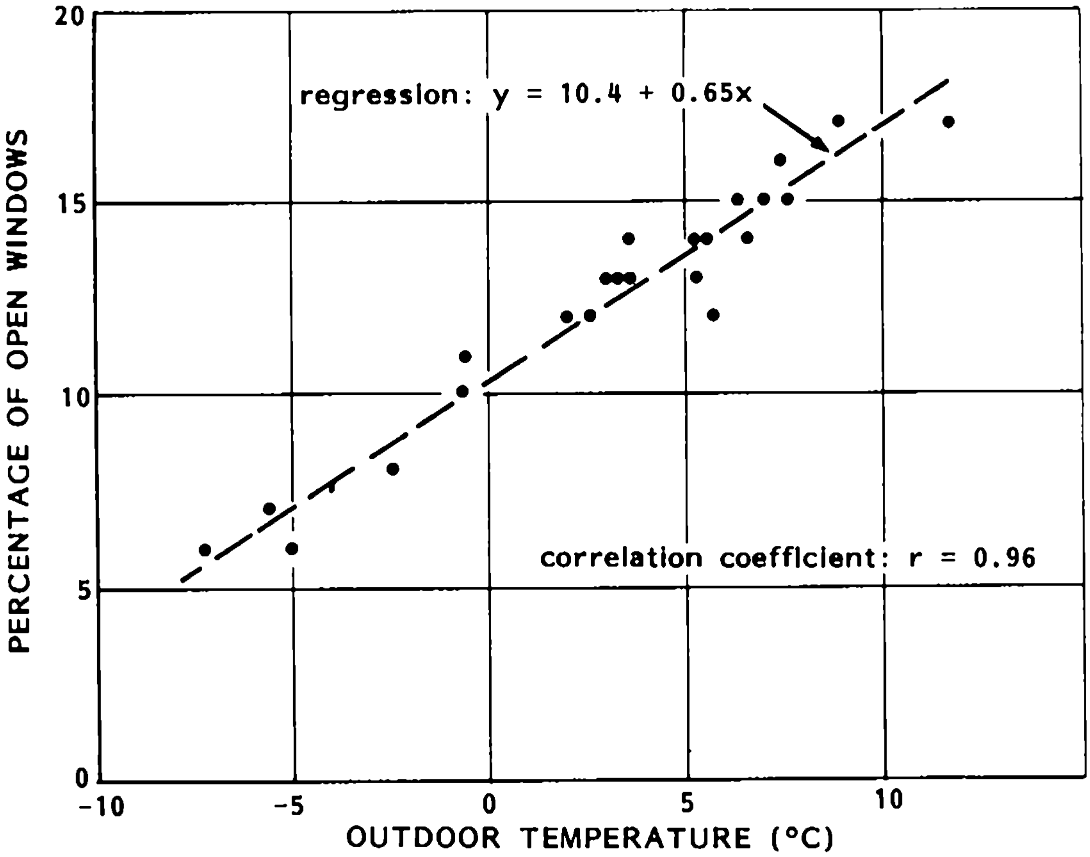



**Figure 2.1: Relationship between the average use of windows and doors and the average outdoor temperature (Schiedam project)**

The regression lines reported in the different projects differed slightly. The main reasons for these deviations were differences in wind velocities and the amount of sunshine, variations in the materials used in the room's construction, and family and other overlapping motivational factors. This direct linear correlation may explain the shape of the curve describing window use throughout the year, which shows the longest window opening times in August and the shortest in January and February. The slope expresses different motivations for window opening.

### 2.5.2 Wind Velocity and Direction

In the Duisburg project an inverse linear correlation between wind velocity and window opening was obtained. Window opening was highest at low wind velocities, independent of the type of room. Above wind velocities of about 8 m/s, nearly all windows were closed. These results were confirmed, in principle, by the investigations in the other countries. Figure 2.2 illustrates the Duisburg findings.

To some extent the type of window adjustment may play a role. The ability to fix the window in a certain position increases the motivation for opening the window.

For a given wind direction, there is obviously a difference between windward and leeward conditions. Windows to windward are kept closed more often than those to leeward.

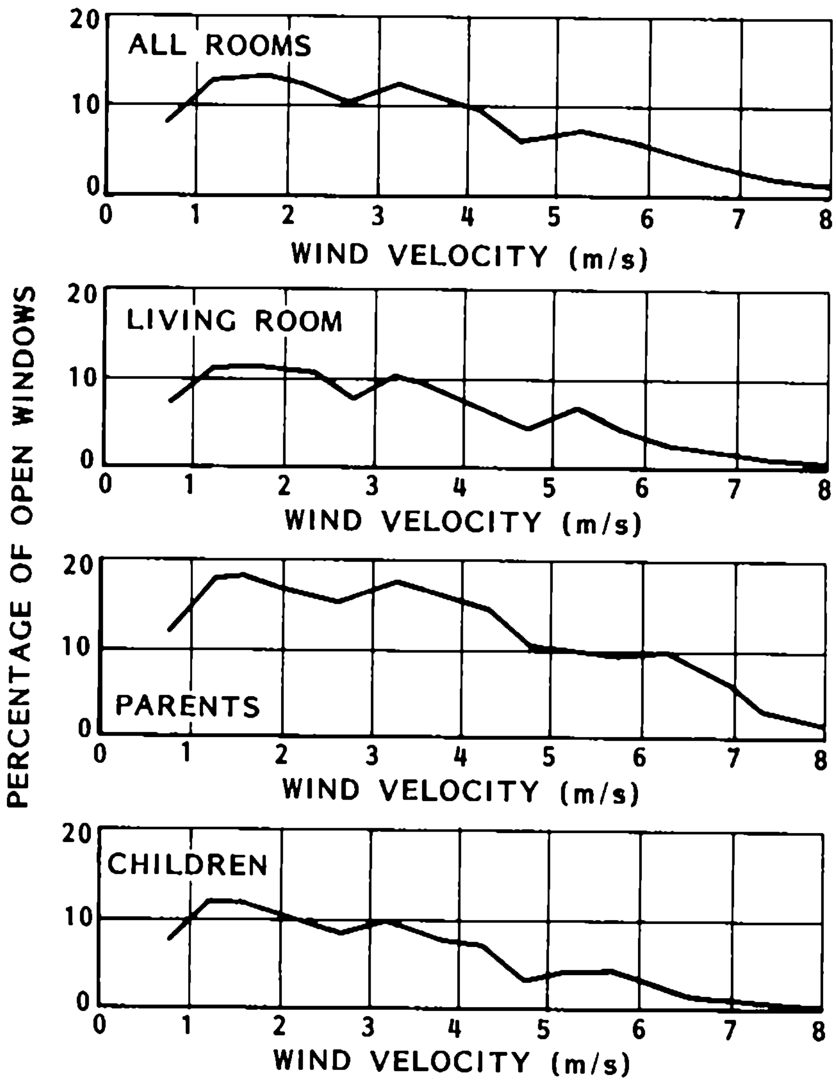



**Figure 2.2: Percentage of open windows as a function of wind speed (Duisburg project)**

2.5.3 Sunshine

The Belgian and Dutch investigations showed that windows were opened more often and for longer periods in sunny weather. Figure 2.3 illustrates this by showing window opening as a function of outside temperature for different levels of solar radiation.

2.5.4 Rain and Precipitation

The levels of precipitation (ie. rain and snow) seem to be significant variables for window opening. Investigations in Belgium showed that window opening intensity for living rooms and bedrooms decreased significantly with increasing precipitation levels. The correlation coefficients were highest for these rooms.

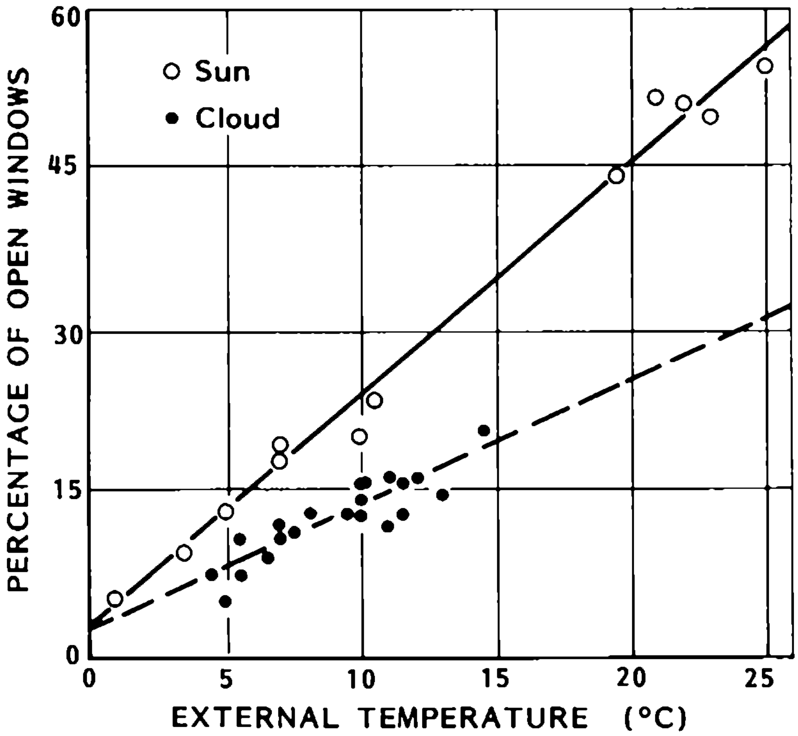



**Figure 2.3: Window opening as a function of outdoor temperature and sunshine**

# CHAPTER 3: Ventilation Rates and Energy Losses Due to Window Opening Behaviour

The previous chapters have sought to examine the way in which occupants use windows for ventilation and to understand the reasons why they do so. The purpose of this chapter is to give some practical, simplified guidelines for estimating air flow rates through open windows. An overview of measured and estimated ventilation rates in houses is given from which a simplified approach is derived that takes into account both the airtightness of the building and behaviour. The second part of this chapter deals with heat losses and seasonal heating demand due to window use. The effect of house type and insulation level is also analysed since the effect of variations in window use on energy consumption can be very important in apartments and well insulated houses.

One of the main objectives of this annex was the estimation of air flow rates and the amount of energy lost due to the ventilation behaviour of inhabitants. In Section 3.1 of this chapter, estimations of air flow through open windows are given. Experimental and practical data for the increase in ventilation rates due to window use are given in Sections 3.2 and 3.3. Finally, section 3.4 gives some results concerning heat and energy losses due to window use.

## 3.1 Air Flow Rates Through Open Windows

The air flow rate through an open window depends upon many factors, including those related to the building and its surroundings as well as the prevailing wind and temperature conditions. Windows also consist of different types, the geometry of which may, for a given area of opening, affect the air flow. For present purposes it is proposed to develop relatively simple guidelines, based upon plausible assumptions, which can be used to estimate, to a first order, the ventilation rates resulting from window use. These will be compared with the limited tracer gas measurements of the effect of window opening on ventilation rate that are available.

It is useful, at this stage, to distinguish between the two main types of natural ventilation:

- cross ventilation, in which spaces within the building are well connected and air flow can readily occur through the building (see Figure 3.1);

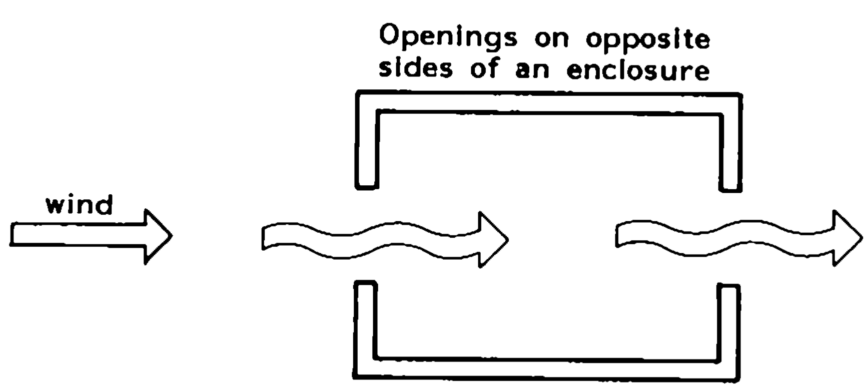



Figure 3.1: Cross ventilation

- single sided ventilation, in which the air flow from a room to the remaining parts of a building is severely restricted in comparison with the flow between the room and outside air. (see figure 3.2)

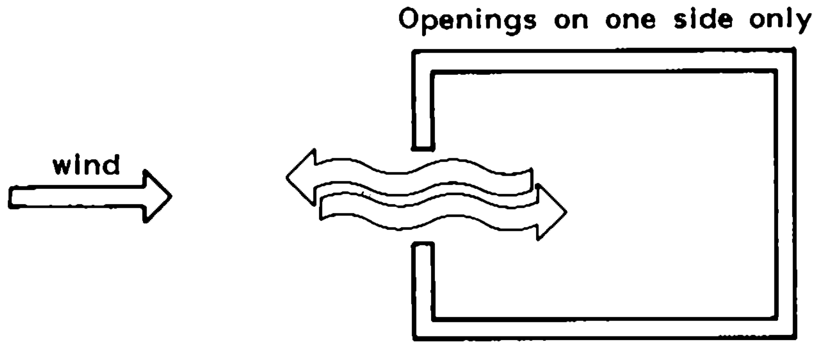



**Figure 3.2: Single-sided ventilation**

In the case of cross ventilation, the ventilation rate of any one room depends on the characteristics of the building as a whole, whereas in single sided ventilation, the ventilation rate is independent of the remainder of the building.

3.1.1 Single Sided Ventilation

The following expression for the volume flow rate of air through an open window due to single sided ventilation can be used:

$$q_v = \frac{A_{open}}{1000} (B \cdot v^2 + 1.400 (T_i - T_e) \cdot h)^{1/2} \qquad (m^3/s) \qquad 3.1$$

where $q_v$ = the volume flow rate
$A_{open}$ = the open area of the window
$B$ = a constant which has a value between 1000 and 10,000 depending on whether the window is sheltered or exposed to the wind
$v$ = wind velocity
$T_i$ = the internal temperature
$T_e$ = the external temperature
$h$ = the height of the window

Phaff et al(61) have derived a similar empirical expression from measurements in Dutch dwellings in sheltered urban situations:

$$q_v = \frac{A_{open}}{1000} (2500 + 250 \, v_{ref}^2 + 900 (T_i - T_e) \cdot h)^{1/2} \qquad (m^3/s) \qquad 3.2$$

Substitution of values for wind speed, $v_{ref}$, and temperature difference, $(T_i - T_e)$, typical of the averaged values for the heating season in the Netherlands, Belgium and the UK, into the above equations yields the following "rule of thumb" for the increase in ventilation rate for single sided conditions:

$$q_v = (0.1 \text{ to } 0.25) \, A_{open} \qquad (m^3/s) \qquad 3.3$$

This generalisation has been further confirmed by measurements of single sided ventilation rate for a range of different window types by other workers(62),(63).

### 3.1.2 Cross Ventilation

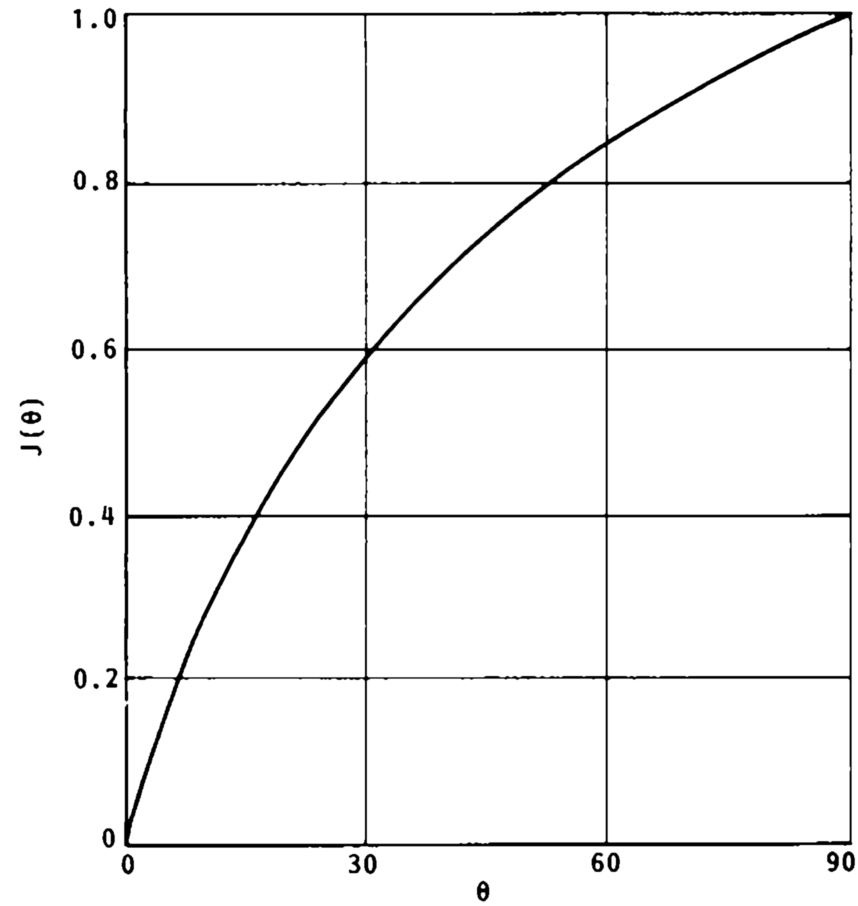
The following general equation has been derived for cross ventilation:

$$q_v = (0.4 \text{ to } 0.8)\ A_{open} \qquad (m^3/s) \qquad 3.4$$

where $A_{open}$ is the summation of the areas of all open windows.

### 3.1.3 Definition of Open Area

The open area of a sliding window is well defined but many windows consist of an opening light which projects out of the plane of the wall. In such cases the "equivalent area" may be obtained by means of a series of measurements under controlled conditions with different degrees of window opening as indicated in Figure 3.3




$$A_{open} = A \cdot J(\theta)$$

where $A = hW\ m^2$

$h$ = height of window

$W$ = width of window

**Figure 3.3: Variation of open area with angle of opening θ**

## 3.2 Average Winter Ventilation Rates due to Window Opening

### 3.2.1 Direct Measurements of the Effects of Occupant Behaviour

Because of the difficulty of making continuous measurements of the ventilation rate in occupied dwellings, results are sparse. However, Kvisgard et al[64] have carried out a programme of measurements, using the constant concentration tracer gas technique, in 25 Danish dwellings, 22 of which were occupied. Typically, measurements were made continuously over a period of one week. 14 of the dwellings were naturally ventilated, 6 had full input/extract mechanical ventilation and 2 had mechanical extract units only. A summary of the results for each of the naturally ventilated dwellings is given in Table 3.1 and for the mechanically ventilated dwellings in Table 3.2.

| N | V ($m^3$) | $n_{inf}$ ($h^{-1}$) | $n_{tot}$ ($h^{-1}$) | $\frac{n_{inf}}{n_{tot}}$ | $\Delta n$ ($h^{-1}$) | $\Delta nV$ ($m^3/h$) | $T_e$ (°C) | v (m/s) |
|---|---|---|---|---|---|---|---|---|
| 1 | 162 | 0.01 | 0.94 | 94 | 0.93 | 151 | 0 | 4 |
| 2 | 184 | 0.12 | 0.52 | 4.3 | 0.40 | 74 | 6 | 4 |
| 3 | 261 | 0.14 | 0.22 | 1.6 | 0.08 | 21 | 3 | 1 |
| 4 | 351 | 0.15 | 0.20 | 1.3 | 0.05 | 18 | 6 | 5 |
| 5 | 271 | 0.15 | 0.27 | 1.8 | 0.12 | 32 | -9 | 3 |
| 6 | 162 | 0.18 | 0.56 | 3.1 | 0.38 | 62 | 3 | 5 |
| 7 | 184 | 0.20 | 0.46 | 2.3 | 0.26 | 48 | 2 | 5 |
| 8 | 130 | 0.22 | 0.43 | 2.0 | 0.21 | 27 | 1 | 6 |
| 9 | 261 | 0.22 | 0.67 | 3.0 | 0.45 | 117 | -5 | 4 |
| 10 | 299 | 0.22 | 0.38 | 1.7 | 0.16 | 48 | -1 | 5 |
| 11 | 130 | 0.25 | 0.59 | 2.4 | 0.34 | 44 | 0 | 6 |
| 12 | 261 | 0.27 | 0.43 | 1.6 | 0.16 | 42 | -8 | 4 |
| 13 | 205 | 0.27 | 0.38 | 1.4 | 0.11 | 23 | -4 | 3 |
| 14 | 139 | 0.32 | 1.08 | 3.4 | 0.76 | 106 | 0 | 5 |
| Mean | 214 | 0.19 | 0.51 | 2.3 | 0.32 | 58 | 0 | 4.3 |
| Standard deviation | 70 | 0.08 | 0.25 | 0.9 | 0.26 | 40 | 5 | 1.3 |

**Table 3.1: Naturally ventilated buildings**

| N | V ($m^3$) | $n_{inf}$ ($h^{-1}$) | $n_{mech}$ ($h^{-1}$) | $n_{tot}$ ($h^{-1}$) | $\frac{n_{tot}}{n_{mech}}$ | $n_{tot}-n_{mech}$ ($h^{-1}$) | $(n_{tot}-n_{mech})V$ ($m^3/h$) | $T_e$ (°C) | v (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 247 | 0.03 | 0.8 | 1.56 | 2.0 | 0.76 | 188 | 7 | 6 |
| 2 | 151 | 0.12 | 0.4 | 0.95 | 2.4 | 0.55 | 83 | 2 | 5 |
| 3 | 271 | 0.12 | 1.0 | 1.1 | 1.1 | 0.1 | 27 | 3 | 7 |
| 4 | 215 | 0.13 | 0.7 | 0.87 | 1.2 | 0.17 | 37 | 8 | 4 |
| 5 | 143 | 0.16 | 0.5+ | 0.81 | 1.6 | 0.3 | 43 | -2 | 6 |
| 6 | 355 | 0.22 | 0.45 | 0.55 | 1.2 | 0.1 | 36 | 5 | 6 |
| 7 | 205 | 0.28 | 0.5+ | 0.80 | 1.6 | 0.3 | 61 | 0 | 5 |
| 8 | 247 | 0.30 | 0.7 | 1.14 | 1.6 | 0.44 | 109 | 8 | 4 |
| Mean | 229 | 0.17 | 0.63 | 0.97 | 1.6 | 0.34 | 73 | 4 | 5.4 |
| Standard deviation | 68 | 0.09 | 0.20 | 0.30 | 0.4 | 0.23 | 54 | 4 | 1.1 |

**Table 3.2: Mechanically ventilated buildings**

A distinction is made between the total air change rate, $n_{tot}$, which includes the effects of occupant behaviour, $n_{inf}$, the basic air change (or infiltration) rate which occurs when the dwelling is unoccupied and all provisions for ventilation (windows, mechanical systems etc.) are shut off, and $n_{mech}$, the air change rate provided by the mechanical system. Table 3.3 summarises the results from both groups of dwellings. It should be noted that for 36% of the time, the total ventilation rate in the naturally ventilated houses was below 0.25 ach, indicating that these Danish houses were probably substantially more airtight than those found in most countries participating in this annex.

| | | **Average** | | **Variance** | |
|---|---|---|---|---|---|
| | | **Natural ventilated** | **Mechanical ventilated** | **Natural ventilated** | **Mechanical ventilated** |
| Dwelling volume | $V$ ($m^3$) | 214 | 229 | 70 | 68 |
| Basic air change rate | $n_{inf}$ ($h^{-1}$) | 0.19 | 0.17 | 0.08 | 0.09 |
| Ventilation rate with ventilation systems functioning | $n_{mech}$ ($h^{-1}$) | — | 0.63 | — | 0.20 |
| Total air change rate | $n_{tot}$ ($h^{-1}$) | 0.51 | 0.97 | 0.25 | 0.30 |
| Increase in air change rate due to occupancy | $n_{occ}$ ($h^{-1}$) | 0.32 | 0.34 | 0.26 | 0.23 |
| Increase in air flow rate due to occupancy | $n_{occ} \cdot V$ ($m^3/h$) | 58 | 73 | 40 | 54 |
| External temperature | $T_e$ (°C) | 0 | 4 | 5 | 4 |
| Wind speed | $v$ (m/s) | 4.3 | 5.4 | 1.3 | 1.1 |
| Mean number of occupants | occ | 2.9 | 2.6 | 1.0 | 0.9 |
| $n_{tot} > 0.25\ h^{-1}$ | (%) | 64 | 99 | 29 | 1 |
| $n_{tot} > 0.50\ h^{-1}$ | (%) | 24 | 77 | 18 | 20 |
| $n_{tot} > 1\ h^{-1}$ | (%) | 9 | 34 | 9 | 22 |

**Table 3.3: Overview of the results**

The increase in ventilation rate due to occupancy, $n_{occ}$, is, on average, 0.32 ach in the naturally ventilated dwellings and 0.34 ach in the mechanically ventilated dwellings. However, as might be expected, there is a large variation between individual dwellings, ranging from 0.1 ach to 0.9 ach. The average increase in air flow rate, resulting from occupancy, varies from 20 to 190 $m^3/h$, with an average of 58 $m^3/h$ for naturally ventilated dwellings and 73 $m^3/h$ for mechanically ventilated dwellings. There does not appear to be any association between the increase in air flow rate due to occupancy and either the basic air flow rate or the dwelling volume.

### 3.2.2 Estimated Effects of Occupant Behaviour

If the average pattern of window use is known for a particular house, then the approximate air change rates determined in Section 3.1 may be used to estimate the resulting increase in average winter ventilation rate. This approach has been applied to the results of an extensive questionnaire survey carried out by Wouters and De Baets on Belgian social housing(66). The survey covered 100 housing estates and responses were obtained for 1115 single-family dwellings and 1219 apartments. The results are described more fully elsewhere(66), but two relevant conclusions may be summarised as follows:

- some 30% of all rooms are never aired (the percentage is lowest for bedrooms but much higher for living rooms);

- the average total daily periods of opening appear to be about 3 h, with higher values for bedrooms and lower values for living rooms. Over all rooms (including those in which windows are never used) the average opening time is 2 h/day.

Using assumptions based on the magnitude of flow rates discussed in Section 3.1, the average increase in ventilation rate due to winter window opening has been calculated for each dwelling in the survey. The overall results for single family dwellings and apartments are summarised in Table 3.4. As indicated by the difference between the mean and median values for each group, the distributions are highly skewed. The higher mean value for single family dwellings results from the fact that the window position was more often found to be wide open, as opposed to slightly open in the apartments.

| Dwellings + Apartments | | Individual Dwellings | | Apartments | |
|---|---|---|---|---|---|
| Mean | Median | Mean | Median | Mean | Median |
| 0.26 | 0.10 | 0.31 | 0.14 | 0.21 | 0.09 |

Mean: arithmetical average        Median: for 50% of the buildings

**Table 3.4: Average Increase in ventilation rate due to winter window opening**

In addition to the Belgian study, a more limited investigation on one apartment building was undertaken in Switzerland(73). This yielded an estimated increase in ventilation rate due to occupancy of 0.25 ach.

### 3.2.3 Overview of Results

Despite the assumptions and approximations made in deriving the estimated additional winter ventilation rates in the three studies discussed above, the results are remarkably similar as shown in Table 3.5.

| Source | Country | Description | $n_{occ}$ (ach) |
|---|---|---|---|
| Kvisgard et al | Denmark | Single-family dwellings<br>• naturally ventilated<br>• mechanically ventilated | <br>0.32<br>0.34 |
| Wouters and De Baets | Belgium | Single-family dwellings<br>Apartments | 0.31<br>0.21 |
| Falst et al | Switzerland | Apartment | 0.25 |

**Table 3.5: Comparison of results for the Danish, Belgian and Swiss projects**

## 3.3 Estimation of Ventilation Rate in Occupied Dwellings in Practice

Using the above results it is possible to derive a simple nomograph, shown in Figure 3.4, for determining typical heating season ventilation rates in dwellings. This is based on the following:

(A) The "basic" air change, or infiltration, rate of a dwelling, in the absence of window opening, may be derived from the air leakage at 50 Pa using the simple "rule of thumb" below:

$$q_{v(inf)} = \frac{q_{v(50)}}{K} \qquad 3.5$$

where $q_{v(inf)}$ is the basic air change rate
$q_{v(50)}$ is the air leakage at 50 Pa
K is a constant which has a value between 10 and 30 (a value of 20 may be regarded as typical). A guide to the appropriate choice of K is given below:

10 < K < 20 : if a combination of at least two of the following characteristics is found:
- high rise building
- exposed situation
- average winter meteorological wind speed greater than 4 m/s
- uniformally distributed leakage area

20 < K < 30 : if a combination of at least two of the following characteristics is found:
- individual terraced houses
- sheltered situation
- average winter meteorological wind speed less than 4 m/s
- leakage area mainly situated at high level

(B) The results of the Belgian survey(66) have indicated that there is no significant association between window use and the leakage characteristics represented by $q_{v(50)}$. Thus:

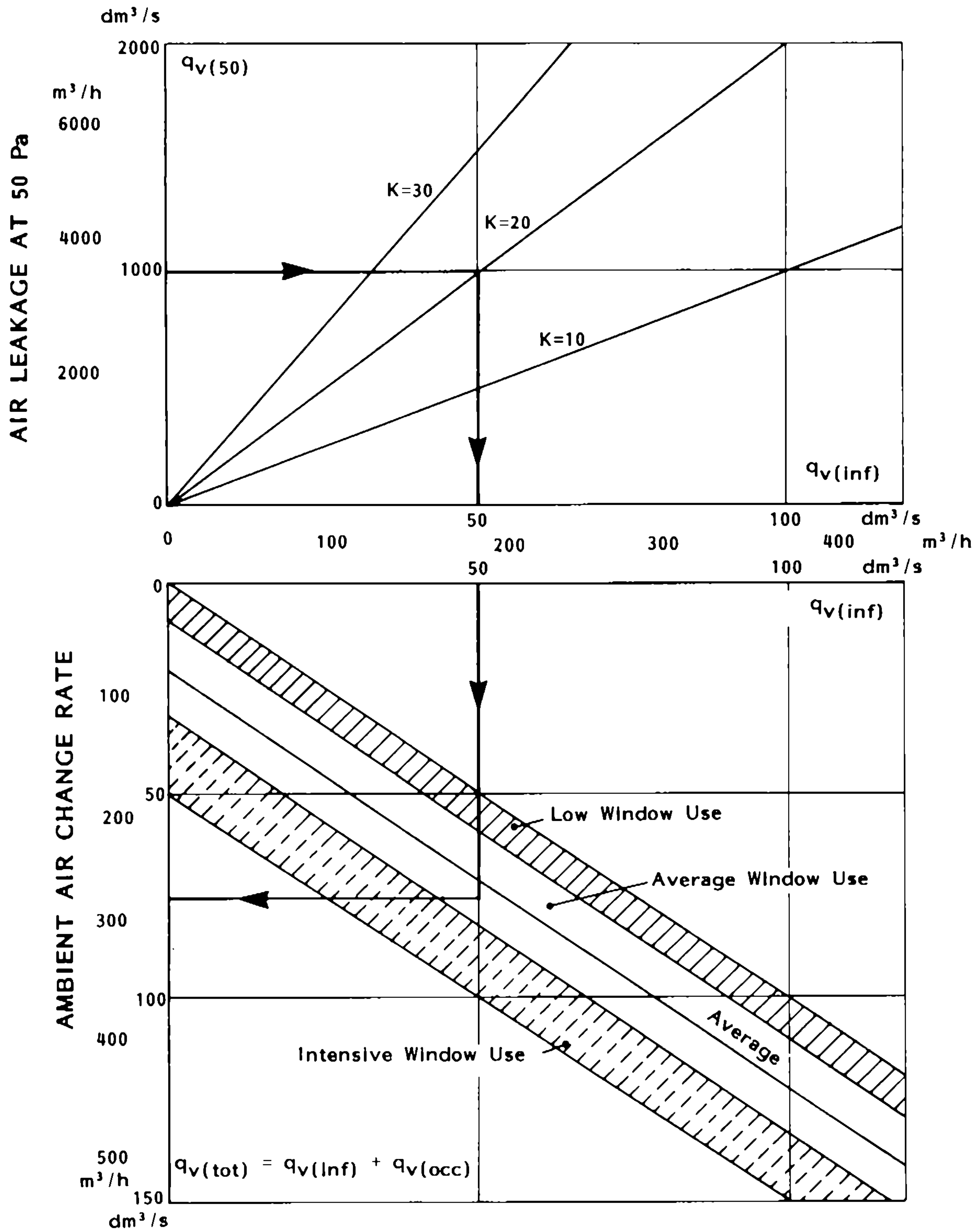



**Figure 3.4: Nomograph for determining typical heating season ventilation rates in dwellings**

$$n_{occ} \neq f\,(q_{v(50)}) \qquad 3.6$$

where $n_{occ}$ is the air change rate due to occupancy.

(C) Similarly, the survey by Kvisgaard et al [64] indicates no significant association between window use and dwelling volume. Thus:

$$n_{occ} \neq f\,(V) \qquad 3.7$$

(D) Further analysis of the studies by Wouters and de Baets [66] and Kvisgard et al [64], discussed previously in section 3.2, provides support for the following possible simple categorisation of additional average seasonal ventilation rate due to window use:

| | | |
|---|---|---|
| Low window use | - | 0.0 to 0.1 ach |
| Average window use | - | 0.1 to 0.5 ach |
| High window use | - | 0.5 to 0.8 ach |

For an average dwelling of volume 250 m$^3$, this leads to the following air flow rates:

| | | |
|---|---|---|
| Low window use | - 0 to 7 dm$^3$/s | (0 to 25 m$^3$/h) |
| Average window use | - 7 to 35 dm$^3$/s | (25 to 125 m$^3$/h) |
| High window use | - 35 to 55 dm$^3$/s | (125 to 200 m$^3$/h) |

The upper limit of high window use is not the absolute maximum value but it will rarely be exceeded in practice.

The following example illustrates the use of the nomograph given in Figure 3.4. If the values of air leakage at 50 Pa ($q_{v(50)}$) and K are known (eg. $q_{v(50)}$ = 1000dm$^3$/s and K = 20) the top part of the figure is used to obtain the infiltration rate. Thus $q_{v(inf)}$ is found to be 50 dm$^3$/s. By extending the $q_{v(inf)}$ value down to the lower part of the figure, the appropriate total air flow can be read off according to the degree of window use. In the example shown, average window use was assumed and a $q_{v(tot)}$ value of 75 dm$^3$/s was found.

## 3.4 Calculation of Heat and Energy Losses

### 3.4.1 Heat Losses due to Ventilation and Infiltration

The heat loss due to ventilation and infiltration can be estimated using the equation:

$$\varnothing_v = (q_{v(inf)} + q_{v(vent)})\,\rho \cdot c \cdot (T_i - T_e) \qquad (W) \qquad 3.8$$

where $\varnothing_v$ = heat losses due to ventilation and infiltration (W)
$c$ = specific heat of air (J/kg/K)
$q_v$ = air flow rates (m$^3$/s)
$\rho$ = air density (kg/m$^3$)

For c = 1000 J/kgK and $\rho$ = 1.23 kg/m$^3$ the above equation can be simplified:

$$\varnothing_v = 1230\,(q_{v(inf)} + q_{v(vent)})\,(T_i - T_e) \qquad (W) \qquad 3.9$$

If the air flow rate, $q_v$, is expressed in $m^3/h$, this equation becomes:

$$\varnothing_v = 0.34\,(q_{v(inf)} + q_{v(vent)})\,(T_i - T_e) \qquad (W) \qquad 3.10$$

Table 3.6 shows the heat losses for an air flow rate of 1 $dm^3/s$ and 1 $m^3/h$ for several temperature differences.

| $T_i - T_e$ | heat losses $\varnothing_v$ | |
|---|---|---|
| °C or K | $W/dm^3/s$ | $W/m^3/h$ |
| 5 | 6.2 | 1.7 |
| 10 | 12.3 | 3.4 |
| 15 | 18.5 | 5.1 |
| 20 | 24.6 | 6.8 |
| 25 | 30.8 | 8.5 |

**Table 3.6: Heat losses for 1 dm³/s or 1 m³/h air flow rate**

### 3.4.2 Seasonal Heating Demand for Ventilation and Infiltration

The seasonal heating demand due to ventilation and infiltration heat loss can be expressed as:

$$Q_v = \Sigma\, 4.4\,(q_{v(inf)} + q_{v(vent)})\,(T_i - T_e) \qquad (MJ) \qquad 3.11$$

or, in other units:

$$Q_v = \Sigma\, 0.34\,(q_{v(inf)} + q_{v(vent)})\,(T_i - T_e) \qquad (Wh) \qquad 3.12$$

where $\Sigma$ = hourly summation over the heating season
$q_v$ = air flow rates ($m^3/s$ or $m^3/h$)

Taking into account the large uncertainty, in practice, it is acceptable to use the degree days approach:

$$Q_v = 1230\,(q_{v(inf)} + q_{v(vent)})\,86400\,.\,DD \qquad (J/ANNUM) \qquad 3.13$$

$$Q_v = 106\,(q_{v(inf)} + q_{v(vent)})\,DD \qquad (MJ/ANNUM) \quad (1) \qquad 3.14$$

where DD = number of degree days over the heating season

Expressed in other units:

$$Q_v = 0.34\,(q_{v(inf)} + q_{v(vent)})\,0.024\,DD \qquad (kWh/ANNUM) \qquad 3.15$$

Table 3.7 gives an overview of classical values of degree days in the participating countries[1].

| Country | Range of Degree-Days DD |
|---|---|
| Belgium | 2100 – 3100 |
| Netherlands | 2600 – 3800 |
| Switzerland | 2500 – 5900 |
| United Kingdom | 1800 – 2600 |
| West Germany | 3200 – 4600 |

**Table 3.7: Variation in degree-days for a number of countries**

For most applications, the number of degree days varies from 1800 to 2600 in mild climates and 2100 to 3500 in more severe climates. Combination of these figures with Equation 3.14 gives the following range in increase in heating demand per $dm^3/s$ increase of air flow rate.

mild $Q_V$ = 190 to 280 MJ/yr per $dm^3/s$
severe $Q_V$ = 220 to 370 MJ/yr per $dm^3/s$

or per $m^3/h$ increase of air flow rate:

mild $Q_V$ = 53 to 76 MJ/yr per $m^3/h$
severe $Q_V$ = 62 to 103 MJ/yr per $m^3/h$

Finally, a very rough estimate of the increase in energy consumption can be made. Table 3.8 gives an order of magnitude for the increase in electricity, natural gas or fuel oil consumption. The approximate assumption for the energy content of the alternative energy sources are given as well as the assumed efficiencies of the heating systems.

| Fuel type | approximate energy content | efficiency of heating system | increase in energy consumption for 1 $dm^3/s$ increase in ventilation rate |
|---|---|---|---|
| electricity | 3.6 MJ/kWh | 95% | 55 to 110 kWh |
| natural gas | 36 $MJ/m^3$ | 60 ... 70% | 8 to 16 $m^3$ |
| fuel oil | 36 MJ/litre | 60 ... 70% | 8 to 16 litre |

**Table 3.8: Approximate estimate of increased fuel use for 1 $dm^3/s$ increase in ventilation rate**

### 3.4.3 The Heat Loss due to Ventilation and Infiltration as a Part of the Total Building Heat Loss

It is common in many countries to assume a total air change rate (ventilation rate + infiltration rate ) of between 0.5 and 1 per hour for the calculation of the heat loss from rooms

Tables 3.9 and 3.10 give the main characteristics of the individual dwellings and apartments analysed in this chapter.

| | | |
|---|---|---|
| floor area | : $100\ m^2$ | |
| room height | : 2.5 m | |
| volume | : $250\ m^3$ | |
| envelope | : $250\ m^2$ | |
| ventilation rate | : $1\ h^{-1}$ | |
| average U-value of envelope | | |
| case 1 | : $2.0\ W/m^2K$ | ($U_{glazing}$ = $5.6\ W/m^2K$, $U_{wall}$ = $1.6\ W/m^2K$) |
| case 2 | : $0.7\ W/m^2K$ | ($U_{glazing}$ = $3.2\ W/m^2K$, $U_{wall}$ = $0.56\ W/m^2K$) |
| case 3 | : $0.4\ W/m^2K$ | ($U_{glazing}$ = $1.6\ W/m^2K$, $U_{wall}$ = $0.34\ W/m^2K$) |

**Table 3.9: Assumptions for individual dwellings**

| | | |
|---|---|---|
| floor area | : $80\ m^2$ | |
| room height | : 2.5 m | |
| volume | : $200\ m^3$ | |
| envelope | : $40\ m^2$ (2 facades 2.5 x 8 $m^2$) | |
| ventilation rate | : $1\ h^{-1}$ | |
| average U-value of envelope | | |
| case 1 | : $4.0\ W/m^2K$ | ($U_{glazing}$ = $5.6\ W/m^2K$, $U_{wall}$ = $3.3\ W/m^2K$) |
| case 2 | : $1.4\ W/m^2K$ | ($U_{glazing}$ = $3.2\ W/m^2K$, $U_{wall}$ = $0.63\ W/m^2K$) |
| case 3 | : $0.8\ W/m^2K$ | ($U_{glazing}$ = $1.6\ W/m^2K$, $U_{wall}$ = $0.46\ W/m^2K$) |

**Table 3.10: Assumptions for apartments**

Some comments on the average U-values are:

case 1 : typical value for an uninsulated building (single glazing, no insulation);

case 2 : typical value for the present insulation level of new buildings (ordinary double glazing, 5cm insulation in walls and roof);

case 3 : typical value for a well insulated building (improved double glazing, 8 to 10 cm insulation in walls 15 to 20 cm insulation in roof).

The higher corresponding U-values for the apartments are due to the high glazing percentage in the facades.

Table 3.11 gives the heat loss for transmission and air change for the three insulation levels above and for an air change rate of 1 per hour.

| Average U-value ($W/m^2K$) | | Transmission losses (W/K) | | Ventilation losses (W/K) | | Ventilation losses as percentage of total losses (%) | |
|---|---|---|---|---|---|---|---|
| House | Apartment | House | Apartment | House | Apartment | House | Apartment |
| 2.0 | 4.0 | 500 | 160 | 85 | 68 | 15 | 30 |
| 0.7 | 1.4 | 175 | 56 | 85 | 68 | 33 | 55 |
| 0.4 | 0.8 | 100 | 32 | 85 | 68 | 46 | 68 |

**Table 3.11: Comparison of transmission and ventilation losses ($n = 1\ h^{-1}$)**

It can be concluded that:

- air change losses are relatively much more important in apartments;

- such losses are becoming more and more important in better insulated buildings;

- the high percentages in the well insulated buildings indicate that untight but well insulated buildings with high air change rates can have heating problems during cold periods with high wind speeds, if the heating system is designed to present standards. This problem can also occur in rooms of well insulated buildings with an overall moderate airtightness, if some of the rooms are rather leaky and/or are on the windward side.

### 3.4.4 The Seasonal Heating Demand for Ventilation and Infiltration as a Part of the Total Heating Demand

An estimation of the effect of air change rates on the seasonal heating demand gives useful information. The heating demands given in this chapter were calculated according to the standardised calculation procedure for the French Region in Belgium.

Table 3.12 summarises the additional assumptions which were made for these calculations.

- Average internal temperature:
  - case 1 : 17°C (house) and 18°C (apartment)
  - case 2 : 18°C (house) and 19°C (apartment)
  - case 3 : 19°C (house) and 20°C (apartment)

- Glazing area:
  - house : 15 $m^2$ of which 6 $m^2$ to South and 3 $m^2$ to East, West and North
  - apartment : 6 $m^2$ to South and 6 $m^2$ to North (including shading)

- Internal gains : 5 $W/m^2$
- Climatic data : Belgian Reference year

**Table 3.12: Assumptions for the calculation of the seasonal heating demand**

The results are given in Tables 3.13 and 3.14. In the reference situation, an air change rate of 0.5 per hour is assumed.

| | | Ventilation Rate ($h^{-1}$) | | | |
|---|---|---|---|---|---|
| U ($W/m^2K$) | $T_i$ °C | 0.5 (reference) | 0.6 (low window use) | 0.8 (average window use) | 1.15 (high window use) |
| 2.0 | 17 | 930 | 950 | 990 | 1050 |
| 0.7 | 18 | 320 | 340 | 380 | 440 |
| 0.4 | 19 | 200 | 220 | 260 | 330 |

**Table 3.13: Heating demand for houses ($MJ/m^2$, year)**

| | | Ventilation Rate ($h^{-1}$) | | | |
|---|---|---|---|---|---|
| U ($W/m^2K$) | $T_i$ °C | 0.5 (reference) | 0.6 (low window use) | 0.8 (average window use) | 1.15 (high window use) |
| 4.0 | 18 | 360 | 380 | 420 | 490 |
| 1.4 | 19 | 120 | 140 | 175 | 240 |
| 0.8 | 20 | 75 | 95 | 135 | 210 |

**Table 3.14: Heating demand for apartments ($MJ/m^2$, year)**

In Tables 3.15 and 3.16 the heating demand due to window use is expressed as a percentage of the total heating demand.

| U (W/m²K) | $T_i$ °C | Low window use | Average window use | High window use |
|---|---|---|---|---|
| 2.0 | 17 | 2 | 5 | 11 |
| 0.7 | 18 | 6 | 15 | 28 |
| 0.4 | 19 | 9 | 23 | 40 |

**Table 3.15: Percentage of total heating demand due to window use for houses (%)**

| U (W/m²K) | $T_i$ °C | Low window use | Average window use | High window use |
|---|---|---|---|---|
| 7.0 | 18 | 5 | 13 | 25 |
| 1.4 | 19 | 15 | 33 | 52 |
| 0.8 | 20 | 20 | 45 | 64 |

**Table 3.16: Percentage of total heating demand due to window use for apartments (%)**

These tables can be interpreted as follows:

- for uninsulated dwellings (case 1), on average, 5 to 13% of the heating demand is due to window use. For uninsulated houses it is rarely more than 10%;

- for moderately insulated dwellings (case 2), on average, 15 to 33% of the heating demand is due to window use. It can reach 50% for high window use in apartments;

- in well insulated dwellings (case 3), on average, 25 to 50% of the heating demand is due to window use;

- in uninsulated dwellings, differences in window use cannot explain the large observed differences in heating demand.

In well insulated dwellings, especially apartments, the ventilation rate due to behaviour has a large effect on heating demand. This means that a precise estimation of the heating demand in such dwellings is very difficult.

It is important to remember that the given data should be used with care because the classification of occupants into three classes (low, medium and high) is rather arbitrary and because all results are average heating season values.

## CHAPTER 4: How can Behaviour be Modified?

### 4.1 Reasons for Modifying Behaviour

In the previous chapter it was shown that, taking into account transmission losses and preferred indoor temperature levels, the use of windows and ventilation provisions, especially where a room thermostat was installed, influenced the amount of energy used for heating.

The mechanism relating window use to energy losses, as derived in Chapter 3, can be used to find the amount of extra energy needed to compensate for losses due to ventilation. If excessive window use was assumed, a maximum value of 17,000 MJ was found for the additional energy needed in a heating season. The total amount of energy used for heating ranges from 25,000 to 150,000 MJ per heating season. For normal ventilation rates a value of 11,000 MJ per heating season was found. In residential studies in this field, the variation in energy use which could be attributed to ventilation behaviour was found to be between 10 and 15%.

The rate of ventilation will also influence indoor air quality. Inadequate ventilation can lead to indoor air quality problems or unhealthy situations, caused by such factors as tobacco smoke or emissions from building materials. The seriousness of these health risks also depends on the degree of background infiltration. Within the framework of the IEA programme on energy conservation in buildings, a report on this subject has been published(4).

The provision of information will, therefore, assist occupants in achieving a balance between energy conservation and indoor air quality requirements and allow them to optimize their ventilation behaviour. Since facilities to allow appropriate ventilation behaviour must be available, information campaigns should also be directed to the builders and developers of dwellings and equipment, and to government administrators.

#### 4.1.1 Information to Builders and Developers

The subjective judgement of indoor air and climate factors by the occupants of dwellings depends not only on the actual air change rate but also on the experienced quality and desirability of the technological and architectural devices in the dwellings. Consequently technological requirements and solutions need to be adapted, as much as possible, to the behavioural patterns and wishes of the inhabitants.

Instead of attempting to define an ideal climate and assign it to the average person, the architect would do better to look for concepts (plan layouts, regulation possibilities etc.) which enable the occupant to satisfy his comfort requirements easily himself according to his own needs and the pertaining environmental conditions. Since there are many occupants, each with their own particular idiosyncracies, measures which allow for maximum behavioural differential should be given priority. If, in practice, there is no scope for introducing innumerable different solutions, then a dwelling and its fixtures should, despite this, be capable of housing a large variety of occupant types. Of interest are measures which include the maximum number of variables, thus safeguarding variety.

Within the perspective of rising usage costs of buildings, it is important to ensure that overheads incurred by technical refinements can be justified by the advantages they offer.

The windows in dwellings are essential in attaining a specific internal micro-climate but they also serve other functions, for example they provide light, make possible visual and auditive contact with the outside world and offer a means of escape. The design of windows and other ventilation provisions should take these factors into account and also allow occupants to create variable air flows of at least 5 $m^3/h$ and to fix windows at any chosen width of opening. To prevent cold, downward air flows from ventilation grilles it is advisable to install these provisions above a heat source.

Although such modifications may be well intentioned in terms of energy saving or cost reduction, it is also very important that occupants should not feel restricted in the way they can control their indoor climate and air quality.

It should be noted that, in Western Europe, the heating season lasts for only half the year and that the need to create comfortable thermal conditions indoors during the summer should be taken into account.

A finding of a German study(21) was that inhabitants did not consider that tilted windows were a ventilation measure. This finding should be taken into account by employing different types of window fittings and by using smaller window openings to prevent unnecessary permanent ventilation while providing ventilation adapted to the occupants' requests.

The effects of information campaigns directed at the producers of ventilation devices and windows, architects, and building and installation companies have not, so far, been explicitly studied. Where no strict government regulations exist, the "free market" is usually the leading force.

### 4.1.2 Requirements for the Design of Systems and Equipment

Findings from the Dutch studies(50),(51),(56) showed that newly developed heating and ventilation systems were insufficiently tested in practice before they were installed. Initially the poor functioning of these systems tended to be attributed, unjustly, to misuse by the occupants. Moreover it appeared that the employees of the installation firms were not familiar with new technological developments. Where information was given by the builder to the user, for example by means of a booklet, this information focused on the operation of the technical system rather than its application to different households.

A German report(5) indicated that, in order to reduce window ventilation and thus heating energy consumption in a dwelling where a mechanical supply/exhaust system was installed, the following minimum requirements would have to be met:

- those concerned must be told about the technology, its method of operation and,in particular, how the installation affects the need for window ventilation;

- the ventilation subsystem must be co-ordinated with the other subsystems which influence the temperature, ventilation and well-being of the occupants;
- the method of operation of the ventilation system must be co-ordinated with broad human needs and habits (eg. the installation should not be noisy, smelly or draughty).

These may be regarded as necessary prerequisites for the introduction of a successful mechanical ventilation plant (ie. one meeting the expectations of the technician and the user) but this does not guarantee that they are adequate. Incidentally, these prerequisites were not satisfied in the building investigated in the German study.

The way that window opening habits are deeply rooted in functional, everyday routines (eg. airing bedding, removal of kitchen smells, sleeping with the window open) and transient basic needs (eg. "fresh air"), constitutes a serious obstacle to the replacement of these habits by a mechanical ventilation system. In further investigations, a thorough study must be made of the extent to which the need for fresh air can be satisfied by a mechanical installation. It is possible that the air introduced by the ventilation plant, in its objective and subjective characteristics, is so different from natural inlet air, especially if it is preheated, that it is not regarded by the user as being qualitatively equivalent.

Another German report[46] considers existing ventilation systems and proposes that a ventilation method claiming to be efficient must meet the following requirements:

- establish hazard-free air quality;
- provide comfort to the user;
- conserve as much energy as is feasible;
- be cost effective.

The first two requirements are compulsory for any system since the establishment of good indoor air quality is the main reason for ventilating a dwelling and any system will be rejected by the user if he feels uncomfortable. The last two requirements, though not compulsory, are highly desirable. The national economists and ecologists are interested in the energy conservation aspects of a system, while cost effectiveness is the yardstick occupants will use in their decisions on an investment.

Air quality and user comfort in dwellings with mechanical systems depend largely of the established air circulation pattern. This pattern was found to be, basically, a function of the location of the inlets and outlets of supply and exhaust air and of the air velocities. Almost every mechanical ventilation system investigated was found to have, to some degree, shortcomings such as:

- unacceptable noise level
- severe draught effects
- high auxiliary energy consumption
- design flow rates not established

- odour transmission from bathroom/kitchen to living rooms
- deficient installations (no acceptance tests performed)
- no maintainance and cleaning provisions
- no directions given to inhabitants (thus ventilation habits unchanged)
- user has no interference option (feels oppressed)

#### 4.1.3 Information to the Legislator and Administrator

Although a general tendency exists in West European countries to "deregulate" building regulations and standards, it should be remembered that many of these regulations originated from the bad housing conditions, health problems and fear of epidemic diseases in the cities in the 19th century. A comparison with housing conditions in the past can easily lead to an under estimation of the necessity of government regulations nowadays. However, new building construction methods, the application of newly developed artificial building materials and furniture, and increased knowledge of health effects still require action from governments. This is especially important in relation to the setting of standards, the delivery of information and the creation of stimulating conditions, so that energy savings and an appropriate indoor air quality and climate in dwellings can be realised.

### 4.2 Information to Occupants and its Effects

From the literature(40) it appears that the expectations from information campaigns aimed at adapting energy-saving behaviour are mostly too optimistic, especially if the campaigns are based on the so-called attitude change or ratio-economic models. The adoption of energy conserving behaviour demands that information must be received, favourably evaluated, understood and remembered by the individual. Short term projects (eg. financial or feedback programmes, preferably on a daily basis) prove more effective in changing behaviour than attitude-change or long term models. The influence of social reference groups is crucial.

A recent Dutch study(48) examined the effects of neighbourhood oriented information campaigns on technical energy saving measures as a function of the rate of cohesiveness of the social networks in neighbourhoods. The neighbourhood social networks were assumed to be a more effective means of diffusing information than the mass media or booklets. From these large scale information campaigns the following conclusions were made:

- the relationship between attitudes and actual behaviour was weak;
- personal comfort preferences were very important;
- financial aspects played a different role depending on the income of the subjects eg. lower-middle income groups were more likely to change their behaviour to save money;
- previous behaviour was a good predictor of future behaviour;
- insulation programmes were poorly implemented by the older age groups and by the lowest income groups

However, when actual behaviour was examined after the neighbourhood information campaign, it was found that the campaigns were less effective than had been anticipated. The investigators ascribed this result to the fact that the information campaign was primarily concerned with retrofitting rather than with energy saving behaviour. The inhabitants concern regarding the expected annoyance and reduction of comfort appeared to be more important than financial profit. An important recommendation was that insulation and other retrofit measures should be conducted efficiently, since any failure was likely to be counterproductive to the information campaign. Before and after the campaign, questions were posed with respect to the use of windows in different rooms. No positive effects were found and, in one project, kitchen windows were opened more often after the campaign. A possible reason for this finding is that the occupants perception of the benefits of insulation negatively influenced their motivation towards other energy saving measures.

Of relevance, in this study, is the finding that before the information campaign was started, the rank order of attitudes with respect to insulation provisions to be installed was as follows:

most positive : crack sealing (weather stripping)
double glazing
insulation of roof
insulation of floor
least positive : insulation of wall

In tenanted buildings, crack sealing, in particular, was viewed as financially profitable, since the installation of the other provisions would increase the rent. This finding is comparable with a Swedish study(47), where it was reported that, of 25 energy saving measures taken by the 78 households investigated, only 3 actions could be said to have affected energy consumer behaviour. The most frequent energy saving activity mentioned was weather stripping of front doors. It can be concluded that minor activities like weather stripping are influenced by assumed economic motives. Major insulation activities like roof insulation are more a question of energy consciousness and knowledge.

An extensive Dutch study(44) examined the effectiveness of different behavioural interventions aimed at promoting energy conservation by consumers. The methods of dispensing information included the use of a booklet containing financial and energy saving information, the booklet + bi-weekly feedback, the booklet + monthly feedback, and the booklet + self monitoring. A control group was also used. The results showed that all the methods were moderately successful and produced a reduction in energy use of between 3 and 5%. In the booklet, the energy conservation tips followed the chronological order of normal household activities. Some advice was given in relation to airing and ventilation including:

| | |
|---|---|
| in the living room | : lower thermostat one hour before airing; |
| in bedrooms | : air in the morning and before heating; 15 minutes airing is usually sufficient; |
| in the kitchen | : do not ventilate for long periods unnecessarily and do not heat before cooking. |

Temperatures of 20°C in the living room and 15°C in the bedrooms were advised and it was suggested that internal doors were kept closed. Some of the findings of the study were:

- if thermostat setting agreements existed within households, specific energy conservation attitudes were more strongly correlated with the natural gas consumption of the inhabitants;

- the greater the occupants' interest in the booklet and the more positive their evaluation, the more effective the booklet was in helping them to conserve energy;

- the hypothesis that there is no significant relationship between consumers' knowledge of residential energy matters, their specific and general energy attitudes and their intentions to conserve energy was rejected.

In the Vlaardingen studies(19),(34) it was found that only 2% of the variance in households' behaviour could be explained by attitudes. It was concluded that individual feedback information was the most effective method of reducing energy consumption but this approach is expensive. Changing attitudes in an energy concious direction should be accompanied by changing consumer acceptance of responsibility and perceived effectiveness and by behavioural recommendations on how to save energy. Home improvements (or technological innovations) like improved insulation should be accompanied by behavioural recommendations for example with respect to the use of windows and doors inside dwellings.

Based on the results of the Vlaardingen(45) study, five clusters of behavioural patterns were distinguished: conservers, spenders, "cool", "warm" and average. The energy use of these clusters differed considerably. The "cool" and "warm" clusters used less energy than the average group. It is recommended that different strategies for changing and maintaining energy related behaviour should be applied to each cluster. It will be clear that this information strategy is appropriate to information about the use of windows and ventilation provisions.

### 4.3 Interim Results of an Information Campaign with Respect to Ventilation

One of the purposes of the Dutch investigation in Schiedam(54) was to give information and instructions to occupants on how to ventilate and air sufficiently, while minimizing the use of heating energy. In November 1986, before the second winter period, all 80 inhabitants received a written example describing how to make proper use of windows. About 10 inhabitants were selected, by means of their measured window use in the previous winter, and visited personally. During these visits, information was given about the energy lost from a large window, open for more than 8 hours a day, and also the risks of not opening windows. In all instructions and talks attempts were made to influence people by means of suggestions rather than strict rules. The written instructions were in the form shown in Table 4.1.

For some inhabitants, the instructions caused more use of windows, while for others, it meant less use of windows. The total effect of the instructions was calculated by splitting up window use, as a function of temperature, into a part before and a part after the instructions. These graphs, for all sixteen windows, are given in Figure 4.2. The dotted line shows the behaviour after the instructions. The codification of the windows is given in Figure 4.1.

As can be seen there is a small total effect for some windows. For instance, after the instruction, the kitchen casement window and the windows in the living room show a more frequent use but in the bedrooms there is no clear decrease in the opening of large windows. Many windows were opened more at low temperatures and less at high temperatures, giving a more constant level of opening. When these figures are considered for all 80 apartments, it can be said that no major energy saving can be expected from the instructions. However, care must be taken when drawing conclusions because, in the study, differences between wide open and slightly open windows were not measured. As changes in the hours open are so small, the total effect on energy saving will depend on how wide windows are open. More analysis of the data is necessary to confirm the provisional results mentioned above.

| **Day:** | **Night:** |
|---|---|
| **Bedrooms** | |
| Large window open 20 minutes (during bedmaking)<br>Ventlight open 1 cm for the whole day | Ventlight half open |
| **Living-room** | |
| When someone is in the room:<br>Either : 2 persons – ventlight half<br>4 persons – ventlight full<br>or : living-room inner door open and some windows in bedrooms and kitchen open | Night (or no one in the room):<br>Windows closed, except with (more) smokers, then a ventlight open |
| **Kitchen** | |
| During cooking:<br>Window as one wishes | After cooking:<br>Either : ventlight open for 20 minutes<br>or : casement window open for 5 minutes followed by an open ventlight |
| **Shower** | |
| Inner door 10 cm open for some hours after use of the shower | |

**Remark:**

For periods of cold weather and strong winds windows can be opened less wide and for shorter times. For periods of warmer weather and weak winds windows can be open wider and longer.

**Table 4.1: Suggested use of windows and doors during normal weather in Spring/Autumn and Winter**

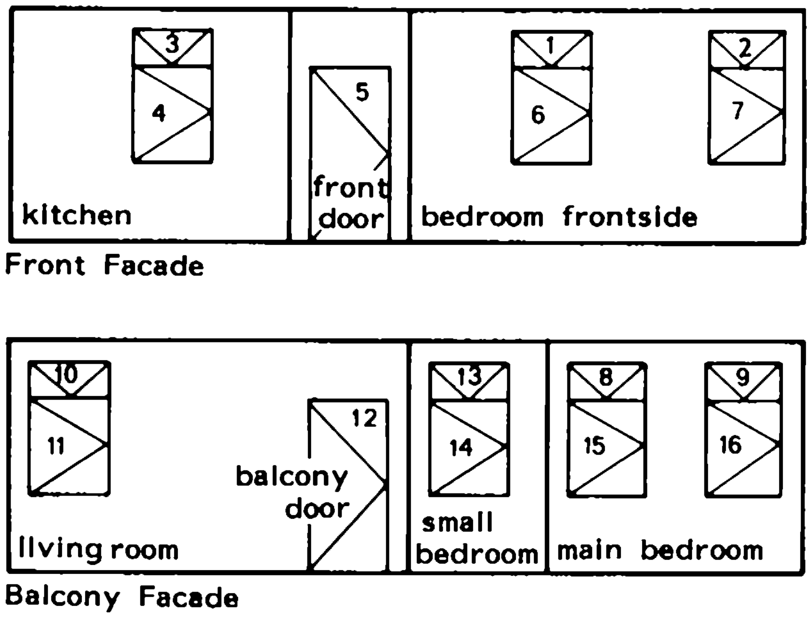



Figure 4.1: Facades and codification of windows and fanlights (Schiedam project)

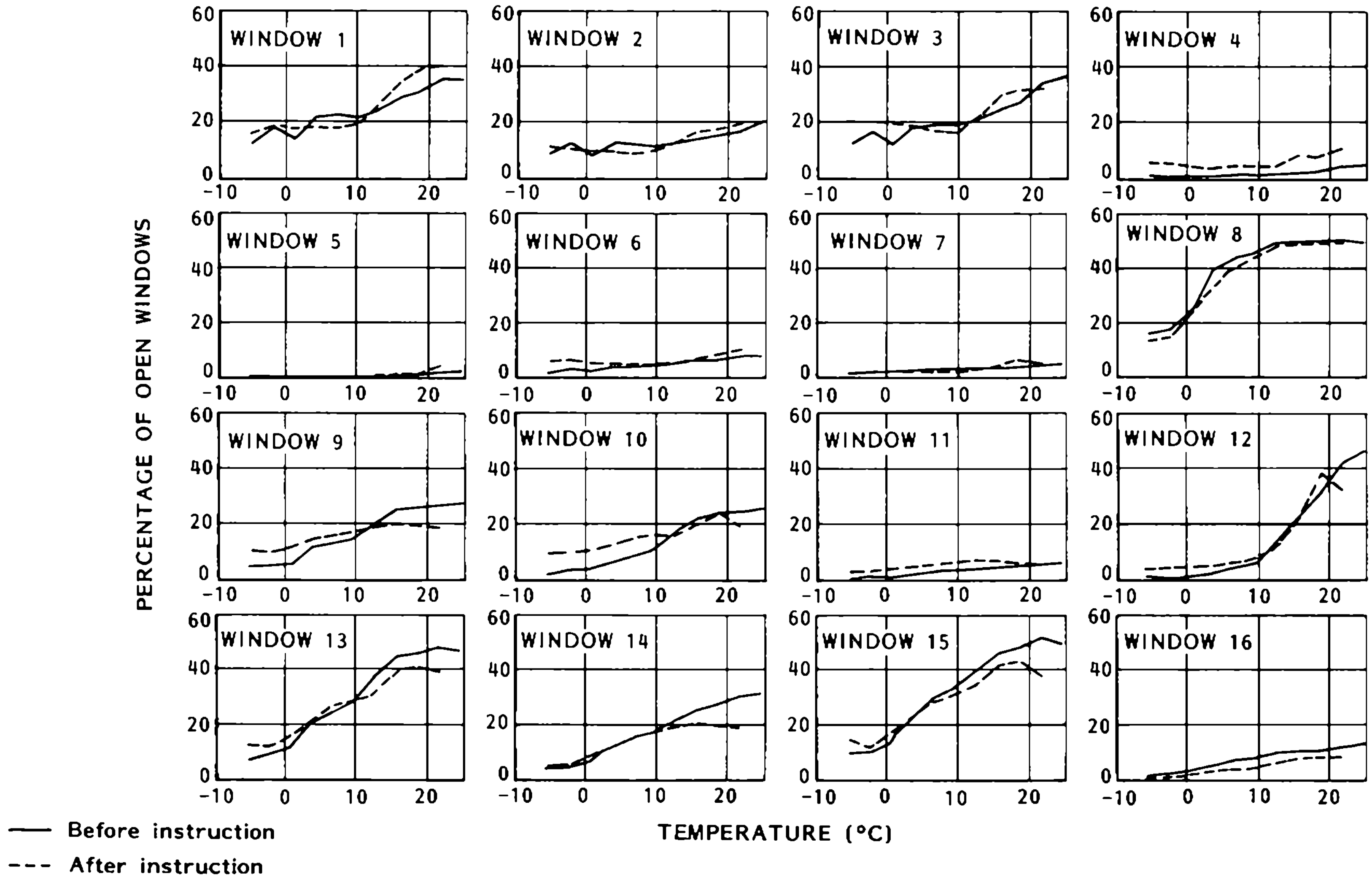



**Figure 4.2: Sixteen windows before and after the instruction as a function of temperature**

## CONCLUSIONS

The results of this investigation have provided a number of findings about ventilation and occupant behaviour, its consequences from an energy point of view, and the suitability and applicability of different methods of influencing inhabitants' behaviour.

From the discussion on "how" and "why" inhabitants of apartments and houses behave as they do with respect to ventilation, it can be concluded that:

- ventilation behaviour (its frequency and duration and its underlying motives) is related to the type of room in which it occurs;

- differences, between households, in patterns of ventilation behaviour appear to be expressed in the form of differences in the type of strategy used to control the indoor environment (eg. its temperature, air quality, and the presence of external noise) in relation to the outdoor environment;

- ventilation behaviour is highly weather dependent but this dependency varies by type of room, also, considerable differences exist between households in their sensitivity to temperature variation;

- ventilation behaviour is influenced by the design characteristics of the dwelling and its heating system. This can occur by affecting the needs of occupants and by making ventilation easier to accomplish.

The general principles of natural ventilation and methods for measuring both ventilation rate and envelope air leakage characteristics were briefly presented in this report, to provide a basis for the discussion of the effect of window use on ventilation rate. Simple, general rules were derived to allow flow through individual windows to be estimated. These, taken with the results of field surveys, were used to estimate the average increase in whole house air change rate resulting from the use of windows during the heating season and the expected range about this average. Some findings were:

- the basic air change of a dwelling, in the absence of window opening, may be derived from the air leakage at 50 Pa using the equation:

$$q_{v(inf)} = \frac{q_{v(50)}}{K}$$

- there is no significant association between window use and air leakage characteristics;

- there is no significant association between window use and dwelling volume;

- further analysis provided support for the following possible simple categorisation of additional average seasonal ventilation rate due to window use;

low window use - 0.0 to 0.1 ach
average window use - 0.1 to 0.5 ach
high window use - 0.5 to 0.8 ach

For an average dwelling of volume 250 $m^3$, this leads to the following air flow rates:

low window use - 0 to 7 $dm^3/s$
average window use - 7 to 35 $dm^3/s$
high window use - 35 to 55 $dm^3/s$

The upper limit of high window use is not the absolute maximum value but it will rarely be exceeded in practice.

- A simple nomograph was derived which allows total average ventilation rates to be calculated from behavioural considerations and from the airtightness characteristics of a dwelling.

It is important to give information to the inhabitants of dwellings so that they may be able to optimize their ventilation behaviour by balancing between low energy use and high indoor air quality. Since ventilation facilities must be available for inhabitants to use in an appropriate way, information campaigns need to be directed at builders and developers of dwellings and devices, as well as to government administrators. Some recommendations in this direction are given in this report.

From the literature, it appears that expectations from information campaigns to adapt energy saving behaviour are mostly too optimistic, if they are based on so-called attitude change models and ratio-economic models only. The adoption of energy conserving behaviour demands that the individual must perceive, favourably evaluate, understand and remember information given to him. Some recommendations in this field are given based on recent quantitative measurements of the effects of an information campaign directed to inhabitants.

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