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Research Report from Germany

Review of Some Research Issues Related to Ventilation of Dwellings in Germany

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Introduction

As a result of the oil crisis in 1973, a great number of investigations and research projects were established in Germany and new regulations set up to help reduce energy consumption in the building sector. It was soon recognised that ventilation losses in dwellings constitute a major part of the heating energy losses in buildings and amount to approximately 6% of Germany's national energy demand – not much less than the energy consumption of all private cars in this country.

Consequently, the investigation programme 'Ventilation in residential buildings' (Lüftung im Wohnungsbau) was begun in 1978. The programme was sponsored by the Federal Ministry for Research and Technology in conjunction with the Federal Ministry for Regional Planning, Building and Urban Development. Its main activities started in 1980.

Even though the basic aim of the programme was to identify possibilities for reducing ventilation heat loss, it was also considered necessary to deal with many other questions which were only indirectly concerned with energy savings. From the beginning therefore, studies of air hygiene, air requirements and emissions from fireplaces, as well as occupant behaviour were included in the programme which thus became an interdisciplinary venture. In the meantime, the focus of public attention has moved from energy conservation to the question of indoor air quality. This move was caused not only by released tensions on the international oil market but also by a growing concern about pollution both inside and outside dwellings.

This article outlines the research programme and discusses selected topics in greater detail. Although all the projects refer to the results of studies in Germany, they should be of relevance to many other countries too.

General review of research programme

The programme is divided into three overlapping phases:

Phase I: Basic studies

- room air pollutants, minimum ventilation rates
- impact of operation of stoves on room air quality
- standard procedures for measurement of air-to-air heat exchangers
- comparison of different ventilation systems in uninhabited experimental houses

Inside this issue:

Phase II: Studies on inhabited houses

- investigations on five inhabited houses with and without ventilation systems and covering inhabitant behaviour, air change rates, air quality, energy consumption, noise level, operational experience.

Phase III: Analysis and evaluation of results

- analysis of natural ventilation systems
- analysis of mechanical ventilation systems
- requirements of buildings, equipment and users if ventilation systems are to be effective.
- comprehensive summary of programme

Phase III is essentially complete with most projects now terminated and reports either published or in the finishing stage except for the comprehensive summary.

An important aspect of the programme is its connection with the International Energy Agency (IEA) within the programme 'Energy conservation in buildings and community systems'. The Federal Republic of Germany is a member of Annex VIII 'Inhabitant behaviour' and of the Air Infiltration Centre (Annex V) and is leading the work of Annex IX 'Minimum ventilation rates'. IEA activities will continue even after the termination of Phase III of the programme.

Some essential results of the programme are summarised within the following ten points.

1. The problem of ventilation in residential buildings is rather complex and involves various branches of technology and industry from building design through construction material production to heating and ventilation systems design. In addition, the cooperation of hygienists and physiologists (cause and effect of harmful substances) is required. Emphasis must be on integrated rather than individual effort.

2. It was discovered that the approach of residents to ventilation is only slightly characterised by objective requirements and is instead marked strongly by individual habits and by subjective feelings. Extremes at both ends of the spectrum (no ventilation or continuous ventilation) are by no means exceptions. Even in houses with a ventilation system fitted, the possible savings in energy are mostly negated by the attitude of the residents, who were generally not sufficiently informed and therefore also not motivated. Therefore, intelligent window ventilation habits cannot be expected of the average inhabitant.

3. Precise and generally valid figures cannot be given for the necessary air change rate since this depends on parameters such as emissions from building materials, air flow pattern and how frequently and in which way rooms are used. However, an average air change rate of 0.5 per hour (in relation to the total volume of the dwelling) should comply with all normal requirements, although zones requiring more intensive or less intensive ventilation may exist for a time during the course of the day (depending on the amount and kind of use). Total ventilation required still remains within the described order. Elimination of excessive pollutant emissions from building materials, cleaning agents, etc. should be considered a problem of the producer and not be transferred to ventilation.

4. With natural ventilation (window ventilation) control is extremely difficult and permanent attendance is required to maintain adequate room air quality whilst avoiding waste of energy. Depending on the effect of fluctuations in wind speed, wind direction and temperature, a variation range of 1 to 20 or more can be achieved easily with the same window position.

5. As a consequence of conservation measures, airtight buildings pose a major safety risk to dwellings with open fireplaces or stoves, if no separate provisions are made for supply air.

6. Considered from both the viewpoint of energy and hygiene, mechanical fan ventilation offers the best solution. If properly designed, it ensures freedom from the influence of wind and temperature, provides the necessary air change at all times and, with only a small amount of electricity needed, permits, with an airtight house, the reclamation of more than half the heat lost by ventilation.

7. Nearly all the ventilation systems investigated have shortcomings, some more serious than others. Typical problems include:

   - unacceptable noise level
   - severe draught effects
   - high auxiliary energy consumption
   - design flow rates not established
   - odour transmission from bath/kitchen to living rooms
   - deficient installation (no acceptance test performed)
   - no maintenance provisions

8. The importance of residents' acceptance of ventilation systems cannot be overemphasised. Systems must be designed for user comfort and ease of maintenance.

9. Present ventilation techniques for dwellings based on the principle of contamination dilution are rejected by many users because of inherent noise and draughts. Instead, 'soft' displacement ventilation techniques which take advantage of natural buoyancy forces can be expected to provide major improvements in ventilation efficiency and user comfort in the future.

10. The design and construction of ventilation equipment currently in use and on the market offers plenty of opportunity for functional improvement and more cost effective production and installation, indeed this improvement must be considered a prerequisite for market penetration.

Natural ventilation

In Germany, natural ventilation (through infiltration and windows but seldom airbricks) is still the dominant method of controlling indoor air quality in dwellings. The only ventilation device commonly encountered is the range hood above the kitchen stove which has no air change effect at all if it is only recirculating poorly filtered air, as is mostly the case. Only a small percentage of all dwellings have stack ventilation or exhaust ventilation, but only for windowless rooms. The number of central systems serving the whole dwelling is negligible. It was therefore considered necessary to evaluate the efficiency and controllability of windows and adjustable ventilation openings (using wind speed, wind direction, temperature difference (ΔT) and opening width as parameters).

A test room was used, about the size of a small living room, with provisions to fit the ventilation devices under test. Tracer gas was used to determine the air change rate (decay method). Wind speed, wind direction, inside/outside temperature and pressure differences were measured.

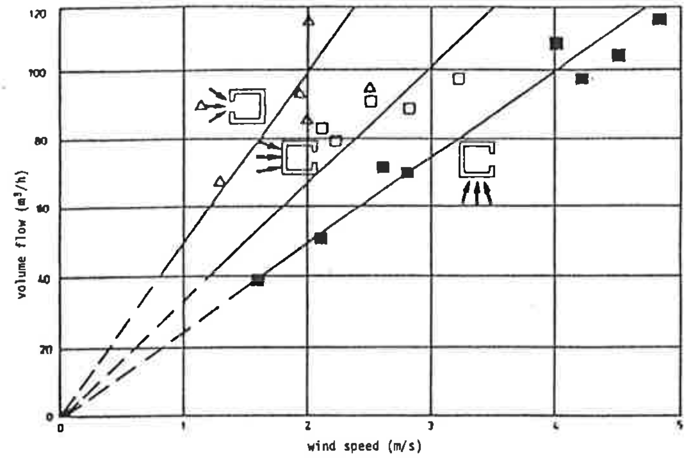

Figure 1: Volume flow through tilted window as function of wind speed and wind direction

Congruent with theory, it was found that (most commonly during the heating season) the volume flow through a tilted single window in an airtight house was linearly dependent on the width of the gap and on wind speed (see Figure 1). Wind direction provides an additional variation range of about 1:2. Cross ventilation with two windows increases the wind induced volume flow by a factor of 5 to 10. By contrast, dependence of volume flow on inside/outside temperature difference (with no wind) follows a square root law (see Figure 2).

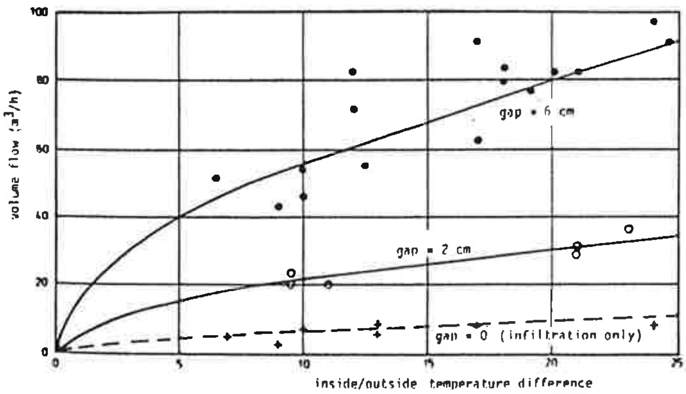

Figure 2: Volume flow through tilted windows as function of ΔT

If both temperature difference and wind are taken into consideration, as is generally the case, no linear superposition is allowed. In some cases even a reduction of the flow volume may result. As a rule of thumb it may be assumed that, for a single open window, wind effects are dominant for wind speeds above 2 m/s, while for wind speeds below 2 m/s and ΔT above 10K, temperature effects play the major part. Figure 3 shows the range of flow volume for a tilted and for a hinged window in three opening positions and with parameter variations as follows:

V $\quad$ = 0 to 6 m/s

ΔT $\quad$ = 0 to 30 K

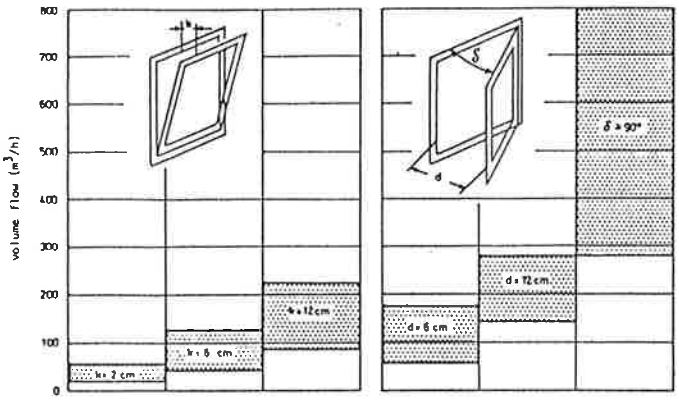

Figure 3: Volume flow range of open windows ($v = 0 - 6$ m/s, $\Delta T = 0 - 30K$)

For controllable ventilation openings, basically the same characteristics apply with regard to wind and temperature influence as for windows. To obtain any perceptible ventilation effect without wind in tight buildings, complementary openings must be fitted as far apart vertically as possible (ideally at floor and ceiling level) to utilize thermal buoyancy effects as driving forces. Figure 4 shows some types of ventilation openings controllable by sliding elements. Most ventilation openings are integrated into windows and some are equipped with acoustic dampers.

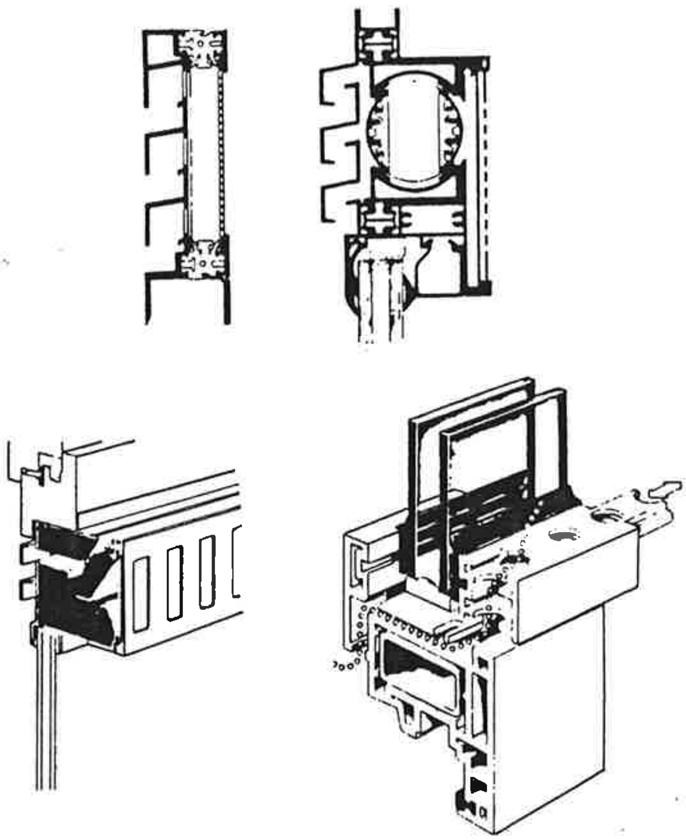

Figure 4: Some types of controllable ventilation devices

One of the shortcomings of typical natural ventilation devices is poor control characteristics (see Figure 5). Whilst a slightly progressive characteristic would be most desirable (case 3), most devices were found to be degressive (case 2). The effective area of the air vents investigated was found to be too small to provide sufficient ventilation. Typical air flow rate of a single device (A = 104 cm^2) without wind was negligible, with two vents at 1.3 m vertical distance and ΔT = 10K it was about 15 m^3/h.

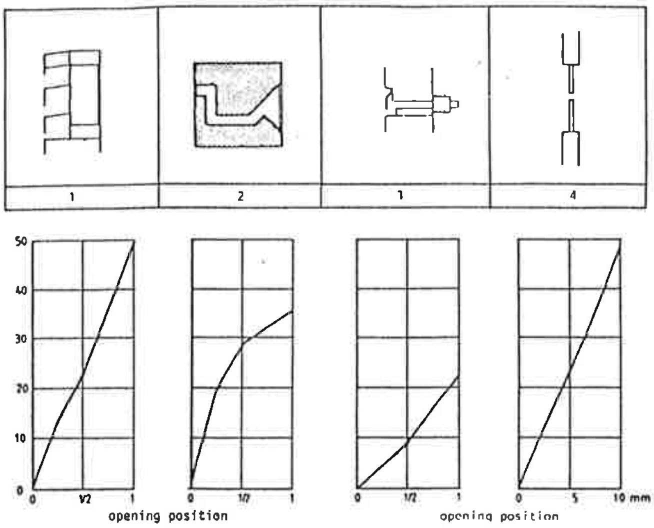

Figure 5: Control characteristics of various ventilation devices

Though it can be concluded that natural ventilation is extremely difficult to control, there are some options for improving the efficiency and handling of such systems, e.g:

- window fittings should allow locking of windows in progressively adjustable narrow-gap positions
- cross section of ventilation openings should be increased considerably
- control characteristics of air vents should be improved
- air vents should be used only in pairs and vertically spaced.

Fireplaces and stoves in airtight buildings

Airtight building envelopes pose a major indoor air quality risk for dwellings equipped with open fireplaces or stoves. To evaluate the general situation in Germany, a project within the Ventilation Programme was designed to assess:

- average and minimum expected infiltration rates in the existing building stock in Germany
- contamination of room air (because stoves depend on indoor air for combustion) as a function of reduced air flow rates

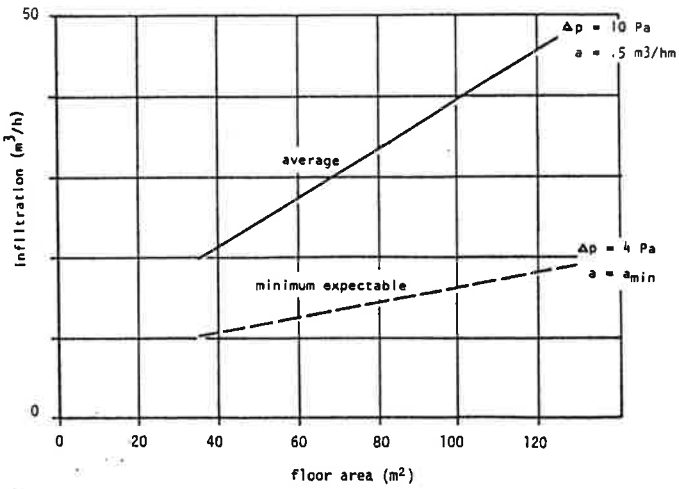

Figure 6: Infiltration rate of dwellings constructed between 1950 and 1980

Since the aim of the project was a risk analysis, emphasis is on the minimum acceptable infiltration. It was found that this minimum is determined by window joints, roller blinds, main door and building element joints. Infiltration through walls or ceilings of brickwork or concrete was found to be negligible and, contrary to general opinion, ageing effects of window sealing strips had no significance. Figure 6 shows infiltration rates for buildings constructed between 1950 and 1980, the dotted curve giving minimum acceptable rates (low leakage coefficients, low outside/inside pressure difference) and the continuous line the average rates. In Figure 7 hourly air changes are shown for the same cases. It can be seen that excessively low rates below 0.1 air changes per hour or 15 m^3/h can be expected if no window ventilation is used. This is a health risk even without stoves in operation.

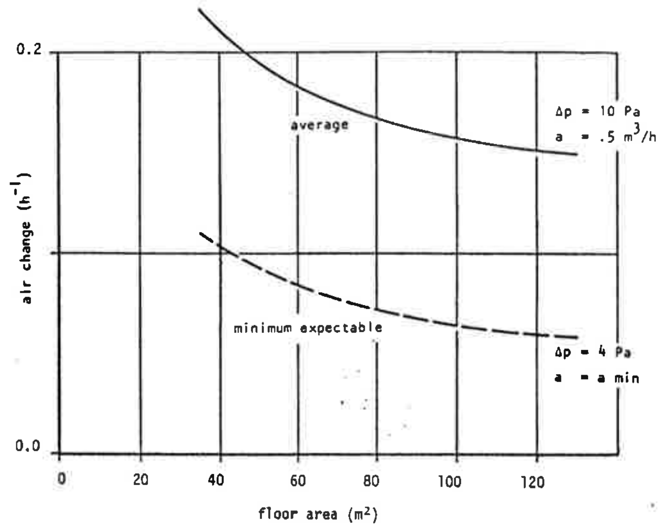

Figure 7: Air change rates of dwellings constructed between 1950 and 1980 (infiltration only)

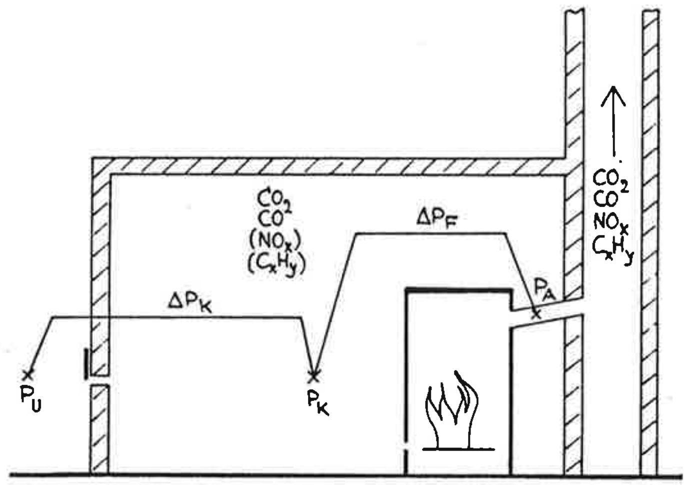

Figure 8: Pressure distribution in test room

To evaluate the operation of stoves under variable conditions, an airtight test room was established with provision for the control of the air flow rate from the exterior into the room and to control pressure P_A in the flue pipe, thus influencing ΔP_F (see Figure 8). Composition of the flue gases was measured, as well as contamination of the room air by flue gas leakages under varying operating conditions. Decisive for the safe operation of stoves is the differential head between room interior and flue pipe (ΔP_F). Various stoves, e.g. solid fuel (wood, coal), liquid fuel (oil) and gaseous fuel (natural gas) have been investigated.

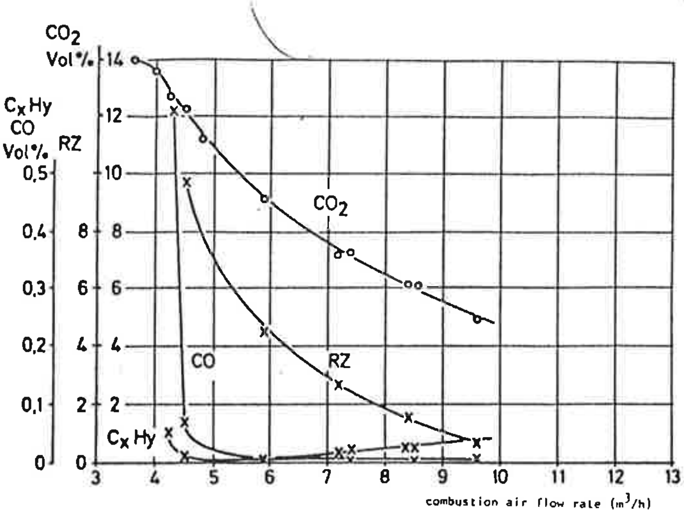

Figure 9: Flue gas composition as function of air flow rate with oil stove under partial load

As an example, Figure 9 shows combustion product concentrations in the flue gas for an oil stove under partial load condition. By contrast, Figure 10 displays room air contamination with CO through a coal stove operating with various differential heads.

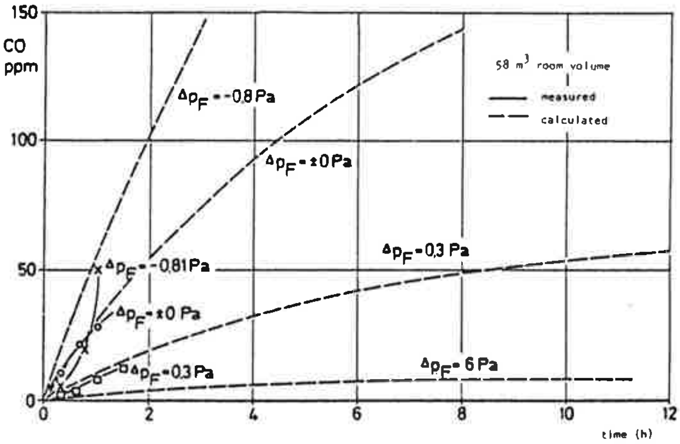

Figure 10: Room air congestion through coal stove for various differential heads

Stoves for solid fuel were found to be self-regulating, i.e. their heating power was governed to a certain degree by varying air flow rates and differential heads. Thus room air contamination under unfavourable conditions was less severe than with oil or gas stoves. It also appeared that emission of flue gases into the room would be reduced by improved/modified construction of most stoves.

Oil stoves have been found to be sensitive to wind influences (with windows or air vents open) as well as to air deficiency (everything closed). This effect was also true of gas stoves, but to a lesser degree, and makes it difficult for them to work properly under all practical conditions.

The only solution to overcome the safety problem for fireplaces and stoves seems to be to provide separate combustion air feeding channels for every unit.

Inhabitants' ventilation behaviour

It was observed that inhabitants' control of ventilation was inadequate. Even in buildings with fitted ventilation systems, no significant changes in attitude have been observed. Figure 11 displays graphically the average ventilation habits of a sample of 230 dwellings during the daytime. Whilst unoccupied bedrooms are ventilated throughout most of the day, kitchens and living rooms in constant use are rather poorly ventilated.

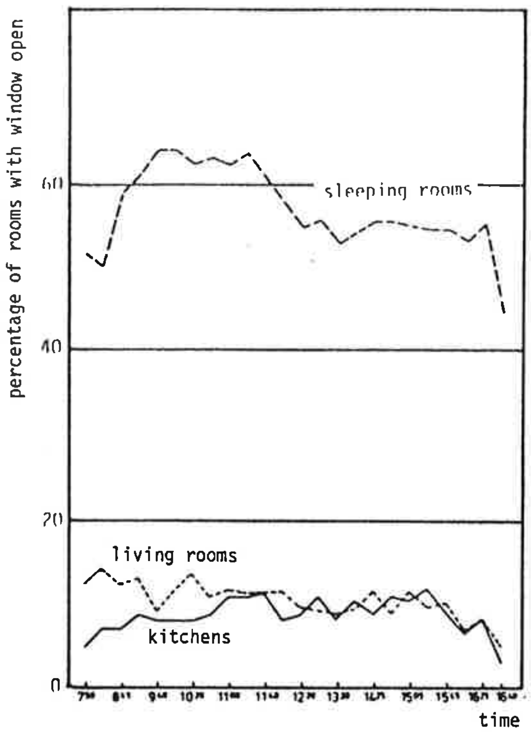

Figure 11: Window ventilation habits

Another more general problem was encountered during the course of these investigations, i.e. the response of inhabitants to inquiries regarding their ventilation habits was definitely unreliable. Figure 12 shows the discrepancy between the estimates of inhabitants and the results of observations. It is therefore highly probable that answers relating to issues other than ventilation are not much more reliable. One must conclude that questions requiring quantitative estimates should be avoided with future inquiries.

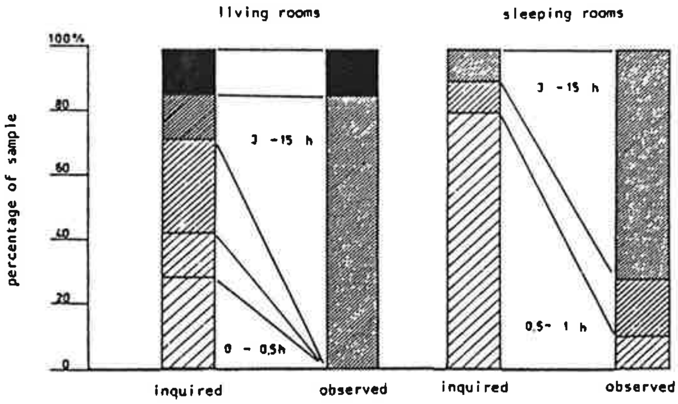

Figure 12: Reliability of inhabitant inquiries regarding duration of window opening

Inhabitants' attitude towards ventilation systems was found to be very conservative to say the least. Causes were not only deficiencies in information and motivation, but must be attributed to a large extent to functional deficiencies of the system itself. Before changes occur in inhabitants' acceptance, considerable improvements in system design and construction must take place.

Requirements for properly designed ventilation systems in dwellings

Complaints about almost every ventilation system have previously been outlined under item 7 in the first section, the most common being draught effects and noise levels. Other shortcomings investigated were comparatively less important. However, these should of course be considered with new systems.

It seems as if conventional (dilution) ventilation systems cannot solve the problem of ventilation requirements. The degree of removal of the polluted air set against the air change rate is low, energy demand and noise level are high and draught effects inherent. The only advantage of dilution ventilation seems to be that it is less susceptible to variations in the ambient conditions of the room interior (due to its forced air circulation pattern) and thus works together with nearly every heating system and tolerates rather wide variations in planning parameters.

More effective 'soft' displacement ventilation systems with much less noise and draught generation are already being used in larger rooms, e.g. conference rooms, theatres, etc. Such systems might be considered a hybrid between natural (buoyancy) ventilation and forced ventilation systems. Displacement ventilation seems to offer a variety of advantages for residential buildings too, where it has not been employed so far.

AIRBASE – the Air Infiltration Centre's Bibliographic Database

Yvette Parfitt, the AIC librarian, describes the Centre's activities in the field of information dissemination and encourages further participation in a valuable international library service.

Introduction

The aims of the Air Infiltration Centre include the cataloguing and transfer of information and full dissemination of current worldwide research in the field of air infiltration. To further these aims, the Centre has established a library of literature, the contents of which are recorded on *AIRBASE*, a computerized bibliographic database. Many of the initial references were drawn from the extensive resources of the library of the Building Services Research and Information Association. Since then it has been continuously updated as new articles are received by the AIC's library. There are presently more than 1,700 references in the database and it is growing at the rate of some 20–30 articles per month. Sources include periodical articles, conference papers, unpublished research papers, books and so on, mainly from the participating countries of the AIC but also from organisations and researchers in other countries active in the field of air infiltration. *AIRBASE* contains articles in over 15 different languages. When an article is considered of particular importance, a translation into English is made and these translations also figure in the AIC database.

Subject Coverage of *AIRBASE*

The main focus of the database is, of course, air infiltration. As such it covers all aspects of the uncontrolled flow of air through cracks and openings in the building envelope, particularly its prediction, measurement and methods for reducing it. Also included are selected papers from the related fields of indoor air quality, occupant behaviour, thermal comfort, ventilation efficiency, natural and mechanical ventilation, wind pressure and its influence on infiltration, and energy saving measures. The principal subjects to be found in the database are:

- tracer gases
- tracer gas measurement by type of building
- tracer gas methods
- pressure tests of leakage of building components
- pressure tests of leakage of buildings
- surface pressures on buildings
- theoretical models of air infiltration and air flow, including comparison of calculated and measured results
- mathematical models
- empirical models
- reduction of heat losses
- energy and buildings
- pollution, air quality and indoor climate
- moisture and humidity
- occupancy effects
- instrumentation and measurement techniques
- the use of heat exchangers
- effects of turbulence