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community systems programme

3rd AIC Conference

Energy Efficient Domestic Ventilation Systems for Achieving Acceptable Indoor Air Quality

Supplement to Proceedings

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AIC

Air Infiltration Centre
Old Bracknell Lane West, Bracknell,
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Annex V Air Infiltration Centre

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3rd AIC Conference

Energy Efficient Domestic Ventilation Systems for Achieving Acceptable Indoor Air Quality

(held at the Park Court Hotel
London, U.K.
20-23 September 1982)

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PREFACE

International Energy Agency

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

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

Energy Conservation in Buildings and Community Systems

The International Energy Agency 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, etc. The difference and similarities among these comparisons have told us much about the state of the art in building analysis and have led to further IEA sponsored research.

Annex V Air Infiltration Centre

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

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

The Participants in this task are Canada, Denmark, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States.

INTRODUCTION

The majority of the papers presented at AIC'S 3rd Conference were prepared in advance and published before the Conference took place. That main document (reference AIC-PRO-3-82) is available from the Air Infiltration Centre at a price of £17 sterling, including postage and packing.

This supplement consists of five additional papers which were included in the Conference programme but were not prepared in time for inclusion in the earlier publication. One of the initial papers (No. 16) required some amendment and the inclusion of diagrams and so it has been reprinted here in full. It is paper E in this document.

Also included here is a report of the discussions that were held at the end of each Conference session. The comments and questions were recorded in writing by the participants and authors were also asked to similarly write their answers. While it cannot be claimed that this method has resulted in a complete record of the discussions, sufficient coverage was obtained to warrant its inclusion in this supplement.

ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER: A

VENTILATION PATTERNS OF WINDOWS AND ADJUSTABLE NATURAL VENTILATION SYSTEMS

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VENTILATION PATTERNS OF WINDOWS AND ADJUSTABLE NATURAL VENTILATION SYSTEMS

R. Daler, F. Haberda, E. Hirsch and U. Knöbel

ABSTRACT

Measurements in a test room of 28.4 m^3 located at the top of a 3-story building have been made to determine ventilation rates of different natural ventilation systems. The systems under consideration were windows which are typical for residential buildings in Germany and various adjustable natural ventilation systems for installation in walls or window frames. The measurements take into account parameters as inside/outside temperature differences, wind velocity and direction, opening position and location of the different systems. The results are interpreted with respect to these parameters.

List of Symbols

A_o	equivalent opening area
C_o	initial concentration of tracer gas
c_t	concentration of tracer gas at time t
d	opening width of pivoted window
f_∇	geometric correction coefficient
g	gravitational constant
k	opening width of balance sash window
K	Kelvin
n	air-change rate
p	pressure
P	barometric air pressure
R	gas constant
t	time
Δt	temperature difference
T	absolute temperature
v	velocity of wind
V	volumetric air flow
V_{ab}	exhaust air flow
V_{zu}	supply air flow
V_l	air flow by infiltration (leakage rate)
V_{Ra}	volume of test room
α	coefficient for flow resistance
χ	factor for calculation of neutral flow axis
ρ_a	density of air, outside
ρ_i	density of air, inside

1. INTRODUCTION

The results presented in this paper have been taken from the work within the project "Natural Ventilation Systems" which is one of momentarily 14 ongoing projects of the research and development program "Ventilation in Residential Buildings". The program is sponsored by the Federal Ministry of Research and Technology (BMFT) of the Federal Republic of Germany. Detailed final reports to each of the projects will be published in German in the "Schriftenreihe Forschungsberichte des Bundesministers für Forschung und Technologie" -BMFT, Postfach 20 0706, D-5300 Bonn 2.

The project Natural Ventilation Systems has been elaborated in cooperation of Dornier System GmbH and Institut für Fenstertechnik, whereby measurements have been accomplished at the facilities of the Institut für Fenstertechnik.

The experience gained from these measurements can be taken to quantitatively judge upon the natural ventilation performance of systems which are common for residential buildings in Germany. The general validity of the results is restricted to some intent to the idealized conditions of a test room. Application of natural ventilation systems in buildings, however, will additionally be influenced by properties of the building and its surrounding. In addition, the behaviour of the inhabitants with respect to control and adjustment of windows and other naturally controlled systems will exert a decisive influence in the ventilation rates obtained in practical application with these systems.

2. PARAMETERS DETERMINING NATURAL VENTILATION

The magnitude of air flows and air-change rates in the test room under consideration which are due to natural ventilation depend basically upon the following three groups of parameters:

A. Driving forces

- temperature differences between inside and outside
- wind acting upon natural ventilation systems and air leakages in the building envelope

B. Natural ventilation systems

- size of opening
- geometry of opening
- internal air flow resistance of system
- position of opening, and location of different openings with respect to each other

C. Properties of test room

- air tightness/leakages with respect to magnitude and position
- positioning of heating elements
- room size, ground plan etc.

The experiments were conducted to give quantitative measures of temperature or wind induced ventilation on various types and positioning of natural ventilation systems.
The properties of the test room, however, were given as constant, apart from efforts trying to minimize the effects of air leakages.

3. DETAILS TO MEASUREMENTS

The test room is located on top of the roof of the "Institut für Fenstertechnik" in Rosenheim (Fig. 1). The test room had a volume of 28.4 m^3. East and west walls of the room were equipped with windows of the combination type balanced sash/pivoted window, which is a quite common window type in Germany. The same walls were equipped at certain periods with variable ventilation slots and adjustable natural ventilation systems. A door leading to the outside was installed at the east wall. The south wall was closed, whereas the north wall apart from a door leading to the interior of the building, had been equipped with a normally closed ventilation slot. This was done to be able to study stack effects due to the height of the adjacent building. Heating was performed by three electrical radiators located beneath the windows. For details see Figs. 2 and 3.

The measurements of the air-change rates applied the concentration decay method with methane (CH_4) as the tracer gas. Air-change (h^{-1}) and air-flow rates $\dot{V}$ (m^3/h) were determined by:

$$n = \frac{1}{t} \ln (c_o/c_t)$$

and $\dot{V} = n \cdot V_{Ra}$,

where c_o and c_t are the concentrations of the tracer gas at time o resp. t and V_{Ra} is the volume of the test room.

The following systems were tested:

- windows of the combination type balanced sash/pivoted at different opening positions, each window having a size of 1.1 m x 1.3 m.
- Ventilation slots having a length of 80 cm. Opening width and position in the test room have been varied
- Four different types of adjustable natural ventilation systems, as available on the German market. Some of them are constructed for noise dampening purposes (see Fig. 13).

The internal flow resistance of the adjustable ventilation systems was determined by using a test device which normally is applied for measurements of the tightness of window seals.

4. MEASUREMENT RESULTS

4.1 Air Infiltration characteristics of the test room

To quantify the air-leakage rate of the test room and its dependence from temperature and wind, several measurements have been conducted with windows and other ventilation systems tightly closed.
The results, plotted in Fig. 4, show that temperature and wind induced natural ventilation is not simply additive. If driving forces due to temperature differences and wind pressure prevail at the same time, then ventilation is mainly determined only by the force which is momentarily dominating. This effect had been stated already theoretically by P.R. Warren, 1976.

Warren, P.R.: Natural Infiltration Routes and their Magnitude in Houses - Part 1:
Preliminary Studies of Domestic Ventilation
Building Establishment, Garston 1976

The air-change rate due to leaks is generally of the order 0.1 to 0.3 h^{-1}. This may seem to be rather high but can be attributed to the small volume of the test room and to the considerable number of leakage sources from several windows, doors and flexible elements for installation of different systems. Nevertheless, by sealing most of the obvious leakage sources, it was tried to keep air leakage as low as possible.

4.2 Balanced sash/pivoted window

To give an idea of the magnitude of air flows caused by different magnitude of window-opening position, the range of all measurement data taken during 1981 have been plotted in Figs. 5 and 6 regardless what outside weather conditions were prevailing. For opening widths k or d of 6 to 12 cm we can expect air flows from appr. 50 to 250 m^3/h. Considering an average sized room of 5 x 4 m^2 floor area having a volume content of 50 m^3 then this would give rise to air-change rates of 1 to 5 h^{-1}, if continous ventilation is applied with this type of window. As nowadays we do not consider continuous ventilation rates of more than 0.5 to 1 h^{-1} to be energy efficient, ventilation by windows with an opening width of 6 to 12 cm should only be applied temporary such as e.g. 5, 10 or 15 minutes per hour. In Germany, however, continous ventilation of certain rooms (e.g. sleeping room during daytime) by a balanced sash of appr. 12 cm opening width is still rather common.
An opening width of 1 to 3 cm seems at first sight more likely to be suited for continous ventilation, but dependence of air flows on temperature and wind still demand an energy-concious behaviour of inhabitants, if excessive energy losses above the necessary limit shall be avoided. The detailed influences of temperature, wind, opening width and positioning of windows will be shown in the following.

To show the temperature dependence of the air flow all measurement data of figs. 7, 8 and 9 have been taken at wind speeds well below 1.5 m/s. As the air flow increases linearily with opening width k resp. d, if these are in the range 0 to 12 cm, the air-flow rates of fig. 9 have been normalized by division through k resp. d.
Details to the theoretically calculated value of the temperature induced air-flow rates are given in the appendix.

The influence of velocity and direction of wind has been studied at inside/outside temperature differences appr. 0 k (Figs. 10, 11 and 12).
Fig. 10 shows a linear dependence of the air change with respect to wind velocity, if wind direction is constant. At the same wind velocity but at different directions of wind there can be considerable differences. The air flow is larger by a factor of appr. 2 between parallel flow direction with respect to window and perpendicular flow to the windward positioned window.
The air flow increases linearly with opening width in the measured range of k = 1 to 6 cm, see Fig. 11.

Fig. 12 shows the effects of cross ventilation with two windows on opposite walls compared to two resp. one window at the same side of the test room. Whereas opening of two windows roughly doubles ventilation caused by one single window, cross ventilation causes ventilation rates to go up by a factor of 8 to 10. In practical circumstances wind induced cross ventilation will not be applied, apart from eventually removing heat loads in summer-time. But we should keep in that cross ventilation effects can cause excessive air-changes, if e.g. one window has been opened at one side of a building and considerable air leakages exist at the opposite side.

4.3 Ventilation slots and adjustable natural ventilation systems

The manually adjustable natural ventilation systems under consideration are common-type systems available on the German market. Mainly they are applied if excessive outside noise levels prohibit opening of sound-proof windows. Fig. 13 gives some data to the construction of these systems. The systems available on the German market are not equipped with any self-regulating devices for the control of air flows such as e.g. automatic variation of air-inlet area with respect to outside temperature or inside/outside pressure difference. Adjustment is purely manual depending upon the individual judgement of inhabitants.

The measurements from the test-bench showed that the efficiency of these adjustable systems can be sufficiently well described by using an equivalent opening area of a ventilation slot. From this reason most experiments were conducted for ventilation slots having a length of 700 mm each and a width of 10 to 20 mm.

Temperature induced ventilation is shown in Fig. 14 and 15 for different positioning of the slots. One horizontal slot exhibits almost no dependence with increase in temperature difference. The increased level of ventilation compared to the leakage rate seems rather to be due to wind effects still present below 1.5 m/s. Two horizontal slots at different height and one vertical slot show a similar temperature behaviour as found for opening of windows.
The dependence on wind velocity for different positions and numbers of slots is given in fig. 16. If all slots are positioned at one side of the room, virtually no difference in the ventilation rates can be seen when the total opening area of each slot arrangement is the same (104 cm^2 for the data of fig. 16). Cross ventilation by slots at opposite sides of the room, yields higher ventilation rates even with the total opening area being the same.

APPENDIX

Calculation of temperature induced air-flow rates

For the calculation the following basic three relationships are used:

Pressure difference of air at different temperatures

(1) $\Delta p = (\rho_{t_2} - \rho_{t_1}) \cdot g \cdot z$

where ρ_{t_i} = density at temperature t_i

g = gravitational constant

z = altitude

Air velocity v due to pressure difference

$$v = (2 \cdot \Delta p/\rho)^{1/2}$$

or by inserting equ. (1)

(2) $v(z) = 930 \cdot \alpha \cdot z^{1/2} \cdot \Delta t^{1/2}$

where α is a factor for the air flow resistance at an opening

Equation of continuity

(3) $\dot{V}_{zv} = \dot{V}_{ab}$

where $\dot{V}_{zu}$ and $\dot{V}_{ab}$ are the air flows to and from a room.

For a rectangular opening (see fig. 17) of dimension BxH we thus get:

$$\dot{V} = \int_0^{\chi H} v(z)\, B\, dz$$

where $\chi \cdot H$ denotes the height of the natural axis.

With $\chi \cdot H = H/2$ and $v(z)$ from equ. (2) this becomes:

$$\dot{V}_{\square} = 220 \cdot \alpha \cdot B \cdot H^{3/2} \cdot \Delta t^{1/2}$$

For the pivoted window (fig. 18) of opening width d we have air flow through a rectangular and triangular shaped area. The total air flow $\dot{V}_d$ is thus given by:

$$\dot{V}_d = \dot{V}_{\square} + \dot{V}_{\Delta}$$

$$\dot{V}_d = (220 \cdot H + 329 \cdot f_{\nabla} \cdot B) \cdot \alpha \cdot d \, (\Delta t \cdot H)^{1/2}$$

where f_{∇} is a geometric correction coefficient for the deviation from an idealized triangular shape.

For the pivoted window - as used in the measurements - of dimensions B = 1.0 m, H = 1.2 m and f_{∇} being 0.7 this yields

$$\dot{V}_{d \, . \, Test} = 540 \cdot \alpha \cdot d \cdot \Delta t^{1/2}$$

The neutral axis of height $\chi \cdot H$ for the balanced sash (fig. 19) has to be calculated from equ. (3). We get the relation:

$$\frac{B}{H \cdot f_{\nabla}} = \frac{4}{15} \left[\frac{2\chi^{5/2}}{(1-\chi)^{1/2}} + 2\chi^2 + \chi - 3 \right]$$

The air flow $\dot{V}_K$ for the balanced sash thus becomes

$$\dot{V}_K = 496 \cdot \chi^{5/2} \cdot \alpha \cdot f_{\nabla} \cdot k \cdot H^{3/2} \cdot (\Delta t)^{1/2}$$

The relative height χ of the neutral axis and the ventilation factor $\chi^{5/2} \cdot f_{\nabla}$ is sketched in fig. 20.
For the tested balanced sash with B = 1.0 m, H = 1.2 m and f_{∇} = 0.7 the relative height χ equals 0.90.
The air flow for the test window is thus given by:

$$\dot{V}_K = 350 \cdot \alpha \cdot K \cdot \Delta t^{1/2}$$

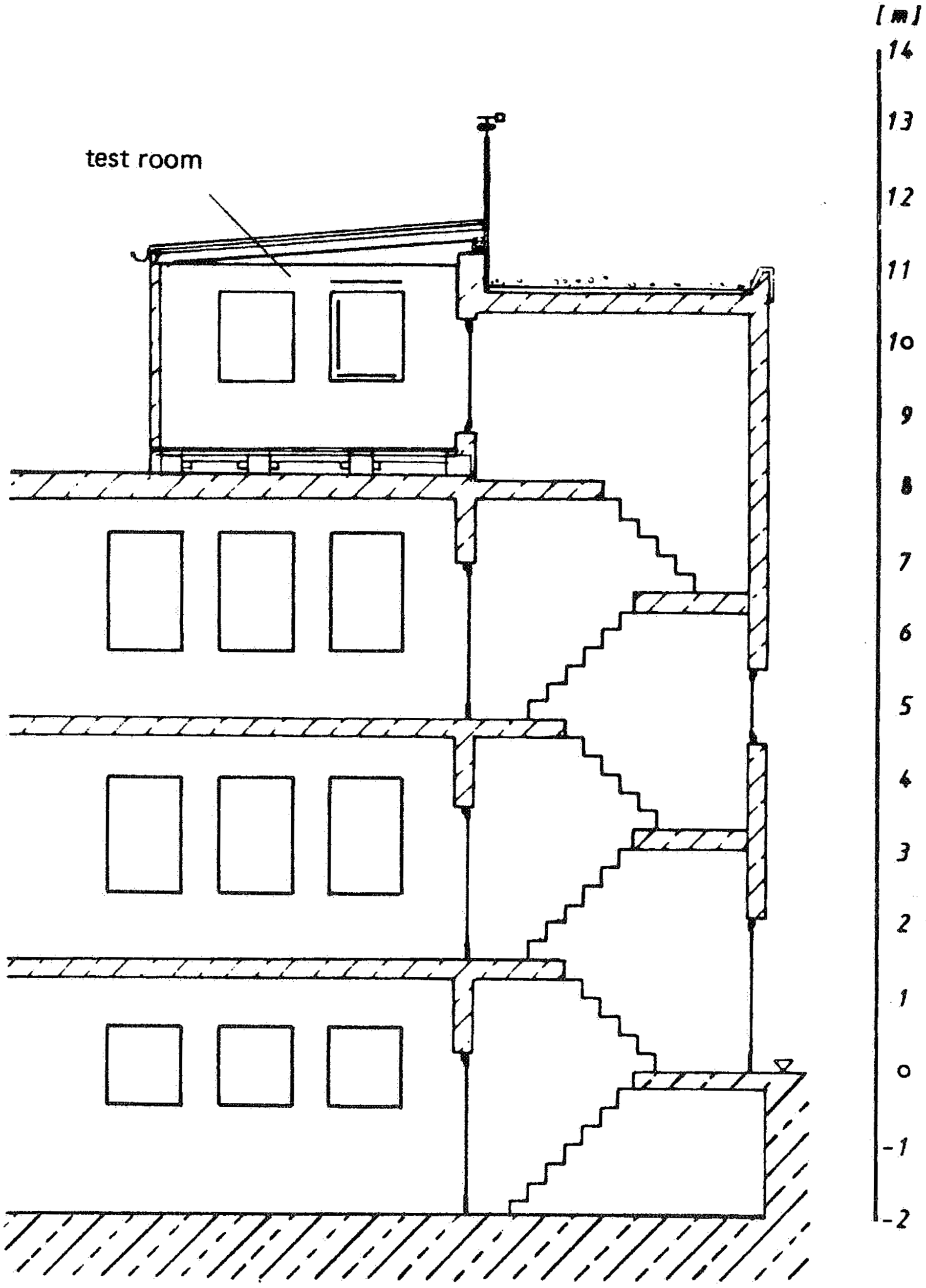
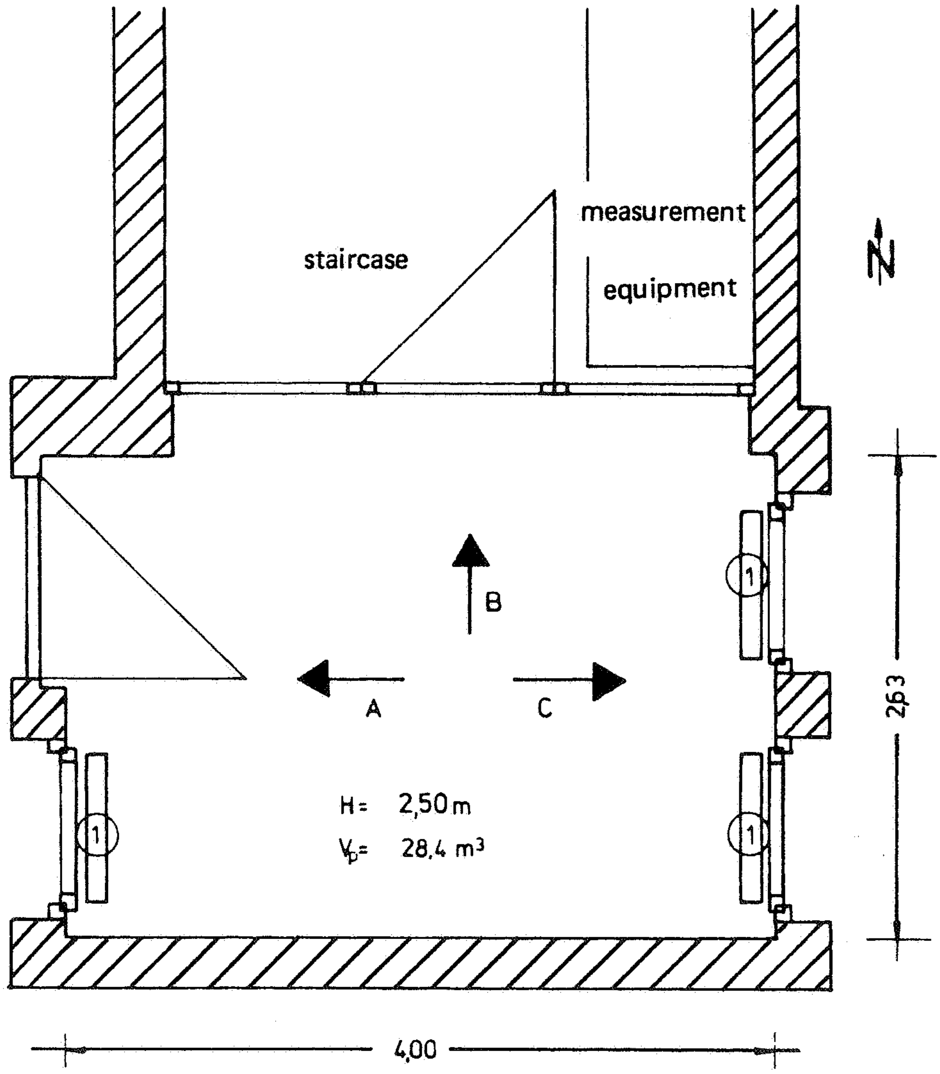
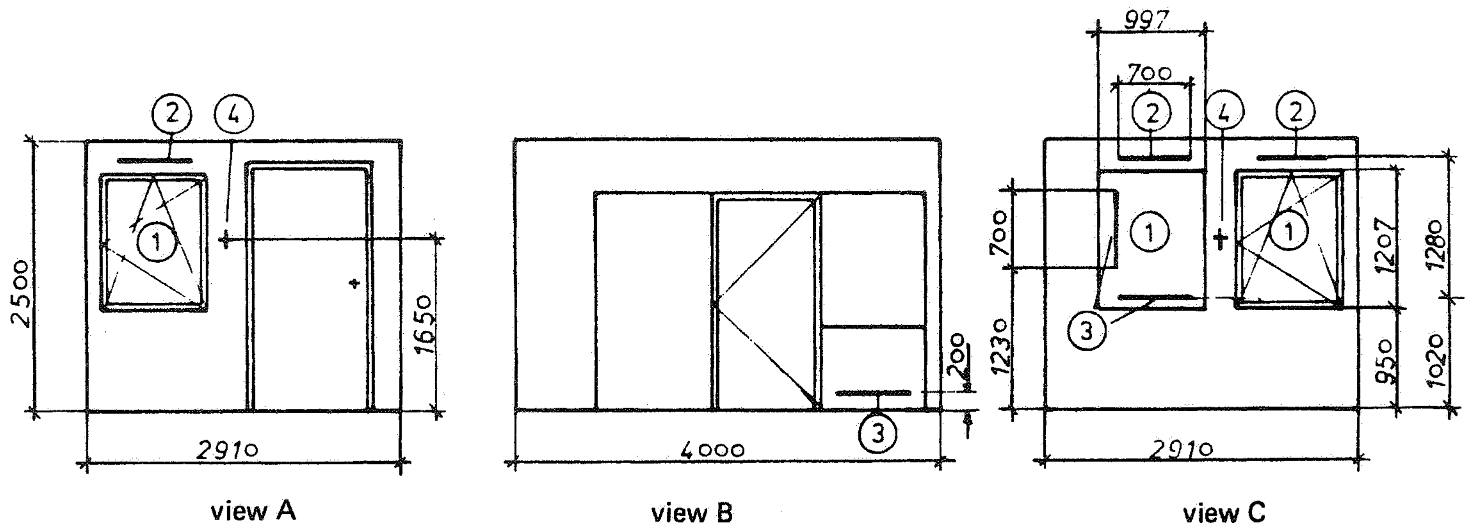


Fig. 1 : Sketch of institute building showing position of test room (view from east)



(1) electrical radiators 1000 W

Fig. 2 : Ground plan of test room
A, B, C indicates views of fig. 3



1 — test windows
2 — installation of different adjustable ventilation units or ventilation slots
3 — installation of ventilation slots
4 — measurement of external pressure

Fig. 3 : **Test room — views of west (A), north (B) and east wall (C)**

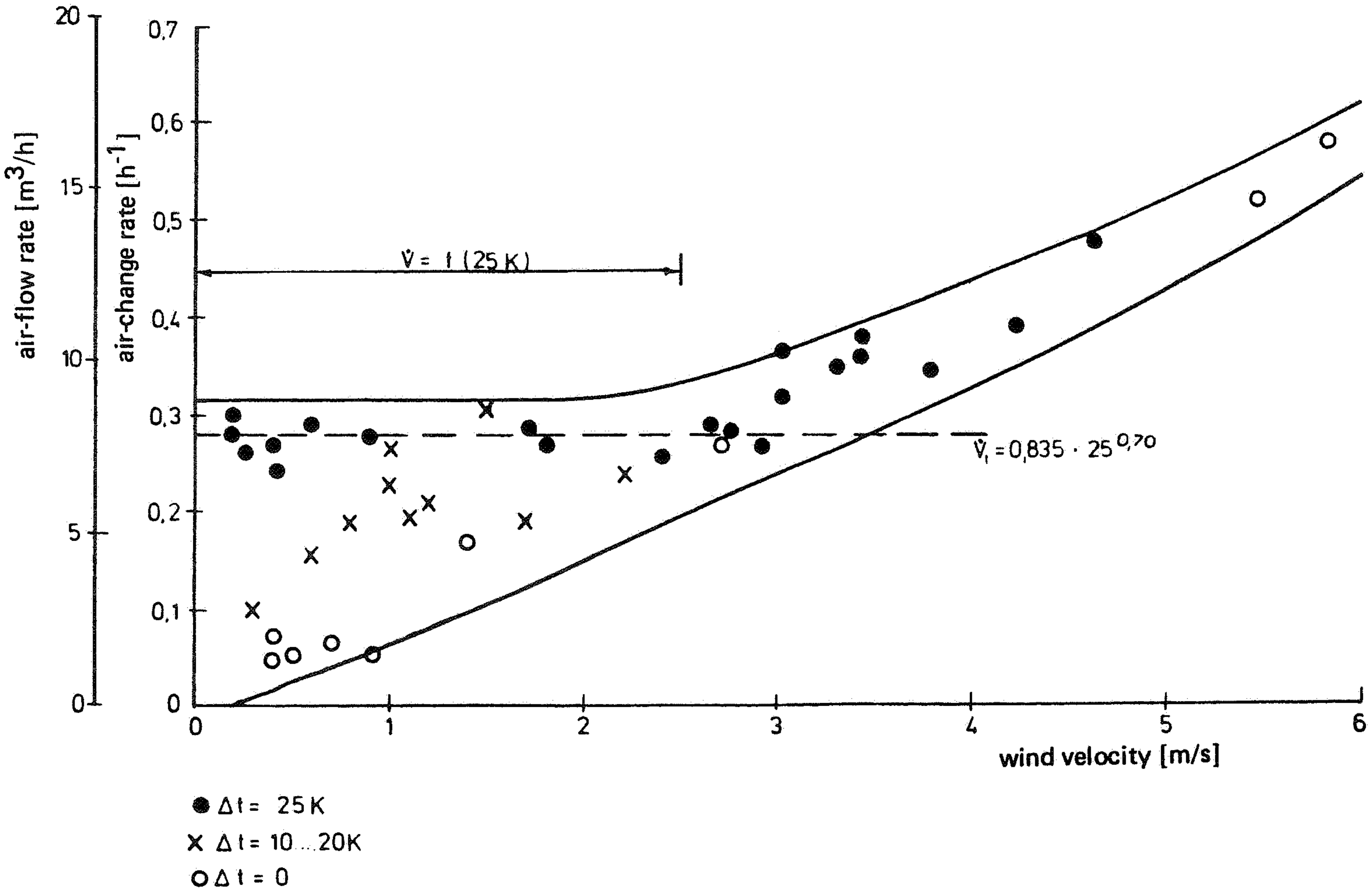


Fig. 4 : **Air infiltration rate through leakages. Dependence on wind velocity at various inside/outside temperature differences**

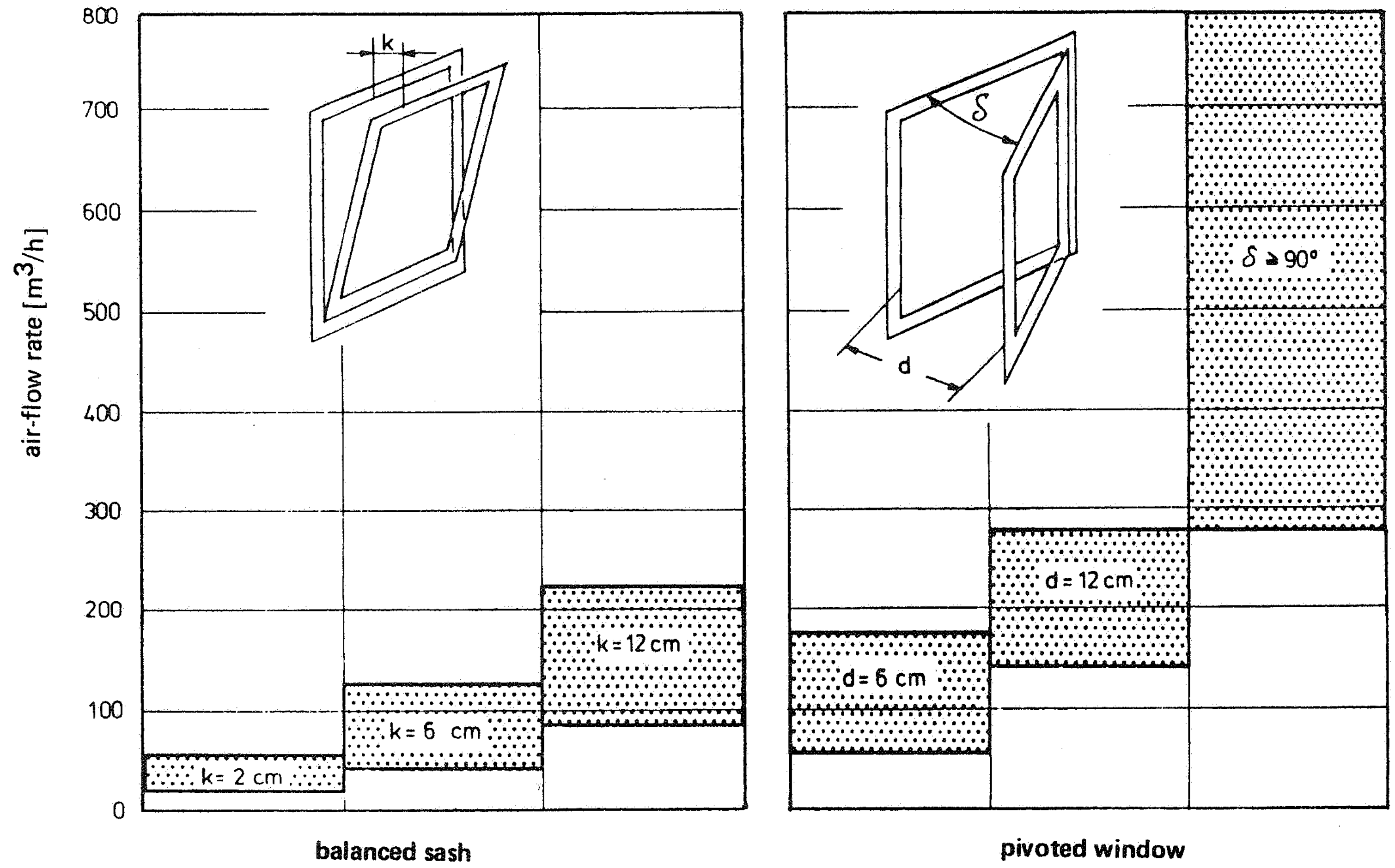


Fig. 5 : Range of all measurement data taken during 1981 for different opening widths of balanced sash and pivoted window.
Wind velocities: 0 to 6 m/s
Inside/outside temperature difference: 0 to 25 K

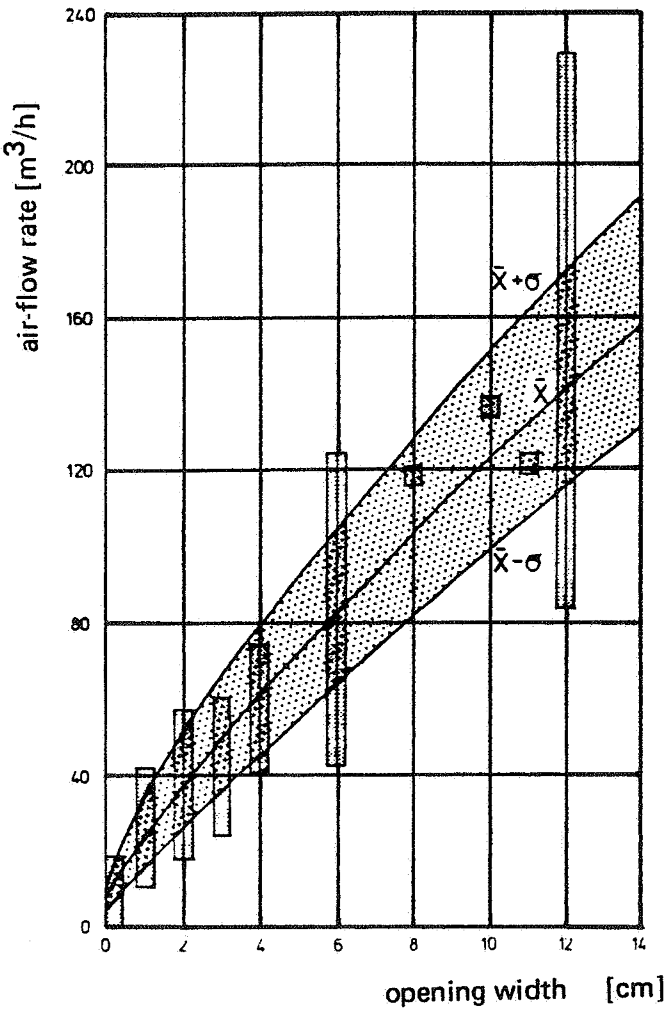


Fig. 6 : Balanced sash window — air-flow rates at different opening widths.
Wind velocities: 0 to 6 m/s
Inside/outside temperature difference: 0 to 25 K

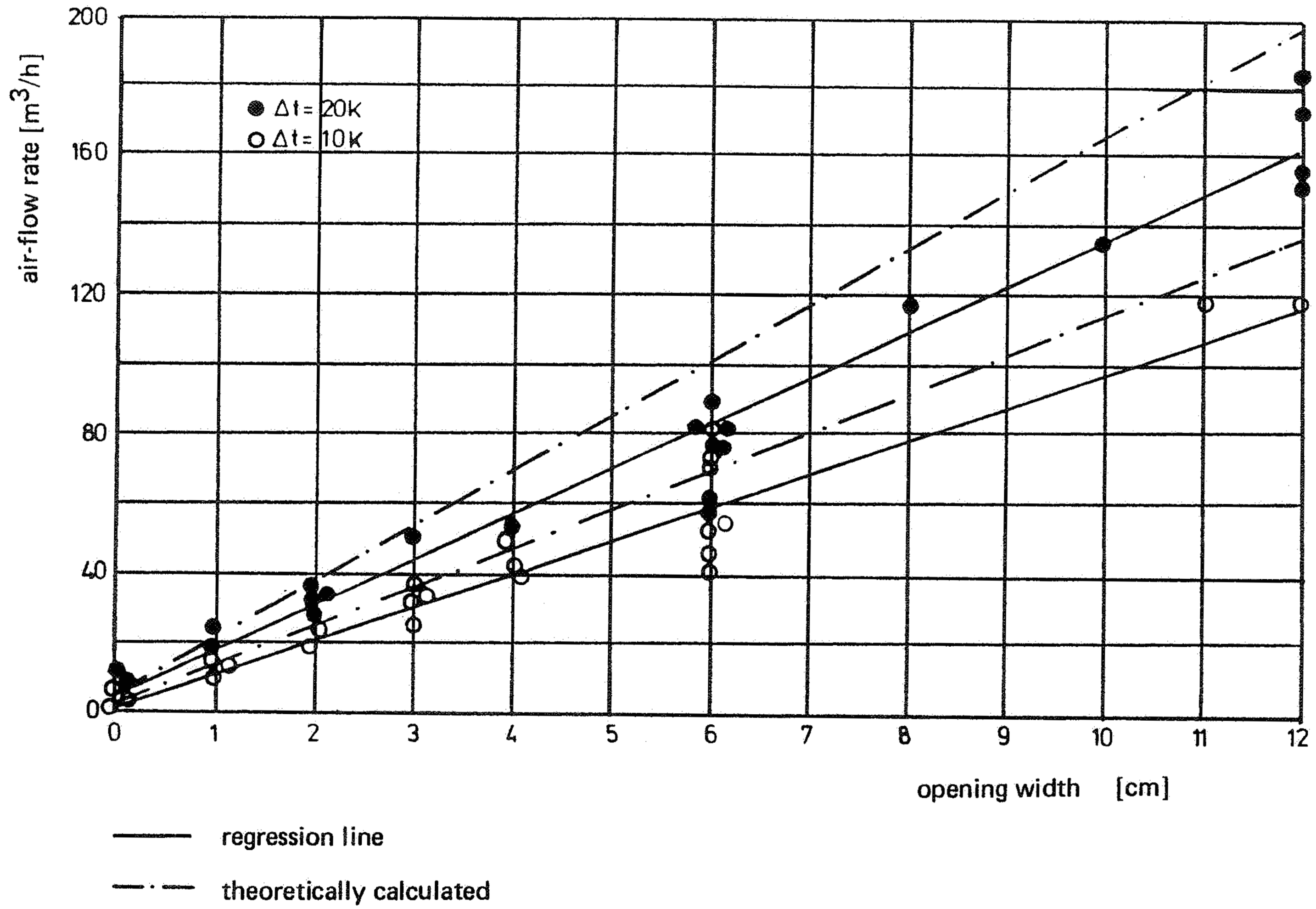
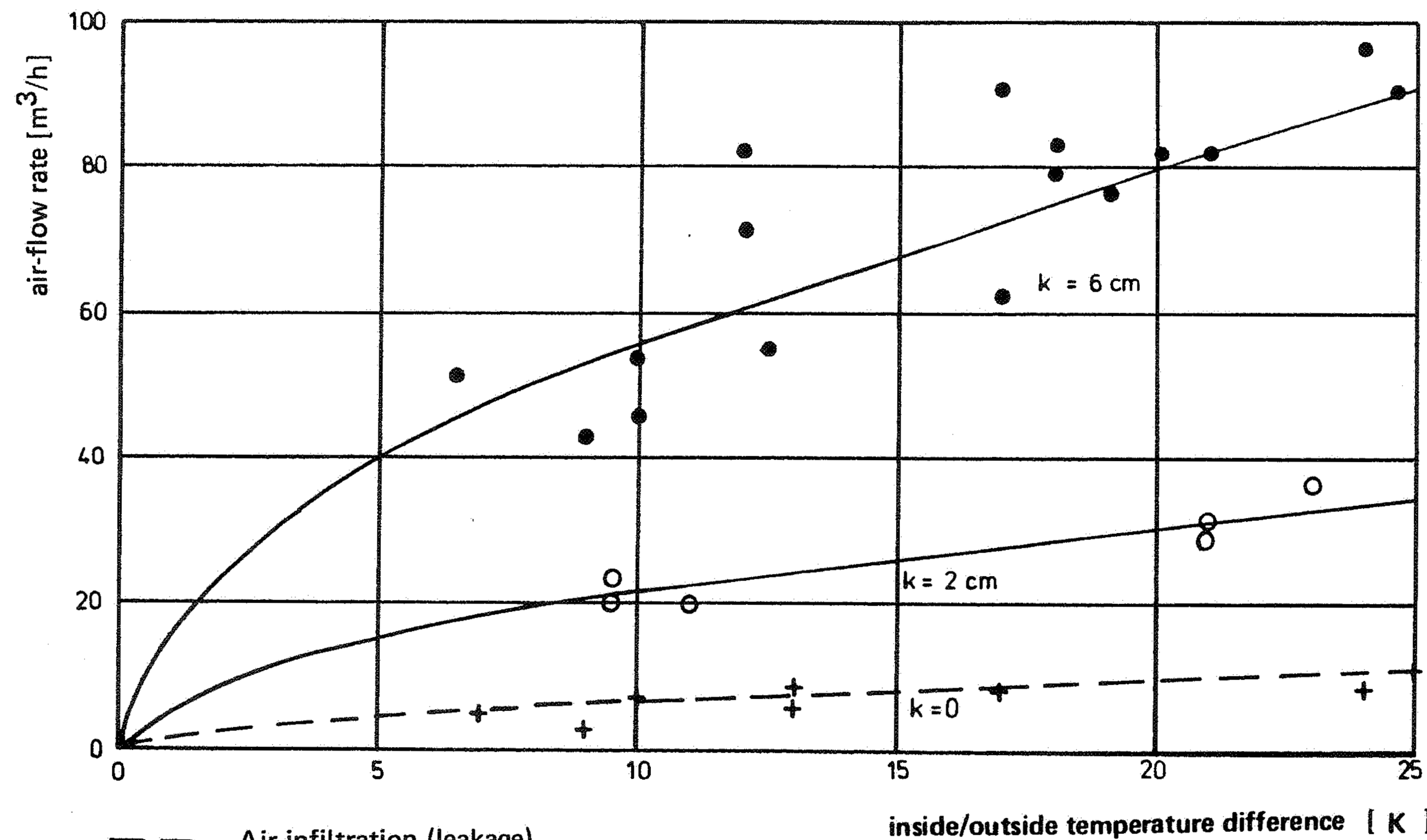


Fig. 7 : **Temperature induced ventilation of balanced sash.**
Dependence on opening width.
Wind velocity below 1.5 m/s



— — Air infiltration (leakage)

—— Leakage rate plus theoretically calculated air flow (coefficient $\alpha = 0.85$)

Fig. 8 : **Temperature induced ventilation of balanced sash.**
Dependence on inside/outside temperature difference.
Wind velocity below 1.5 m/s

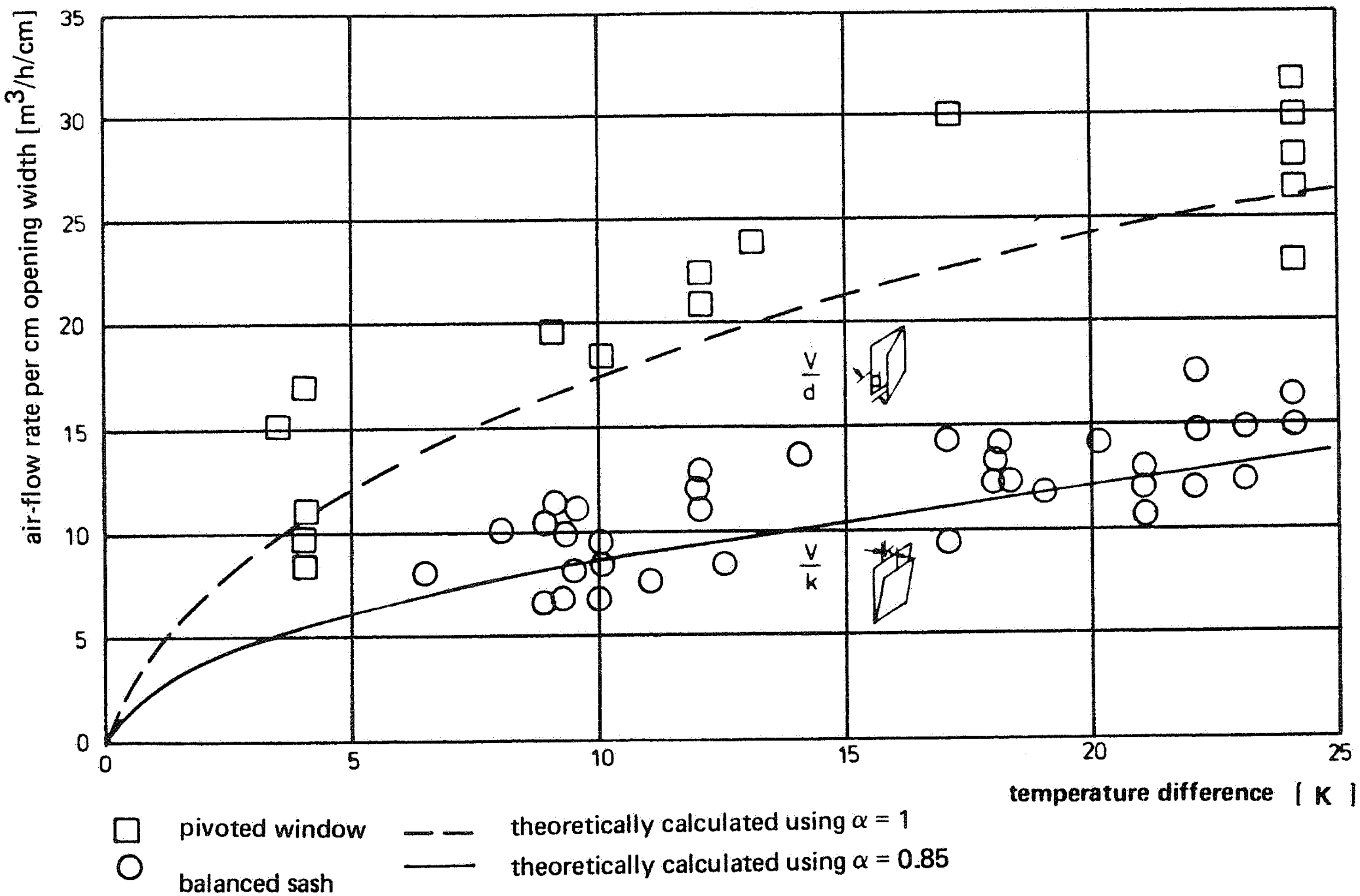


Fig. 9 : **Temperature induced ventilation of balanced sash / pivoted window. Dependence on inside/outside temperature difference of air-flow per cm of opening width d resp. k. Wind velocity below 1.5 m/s**

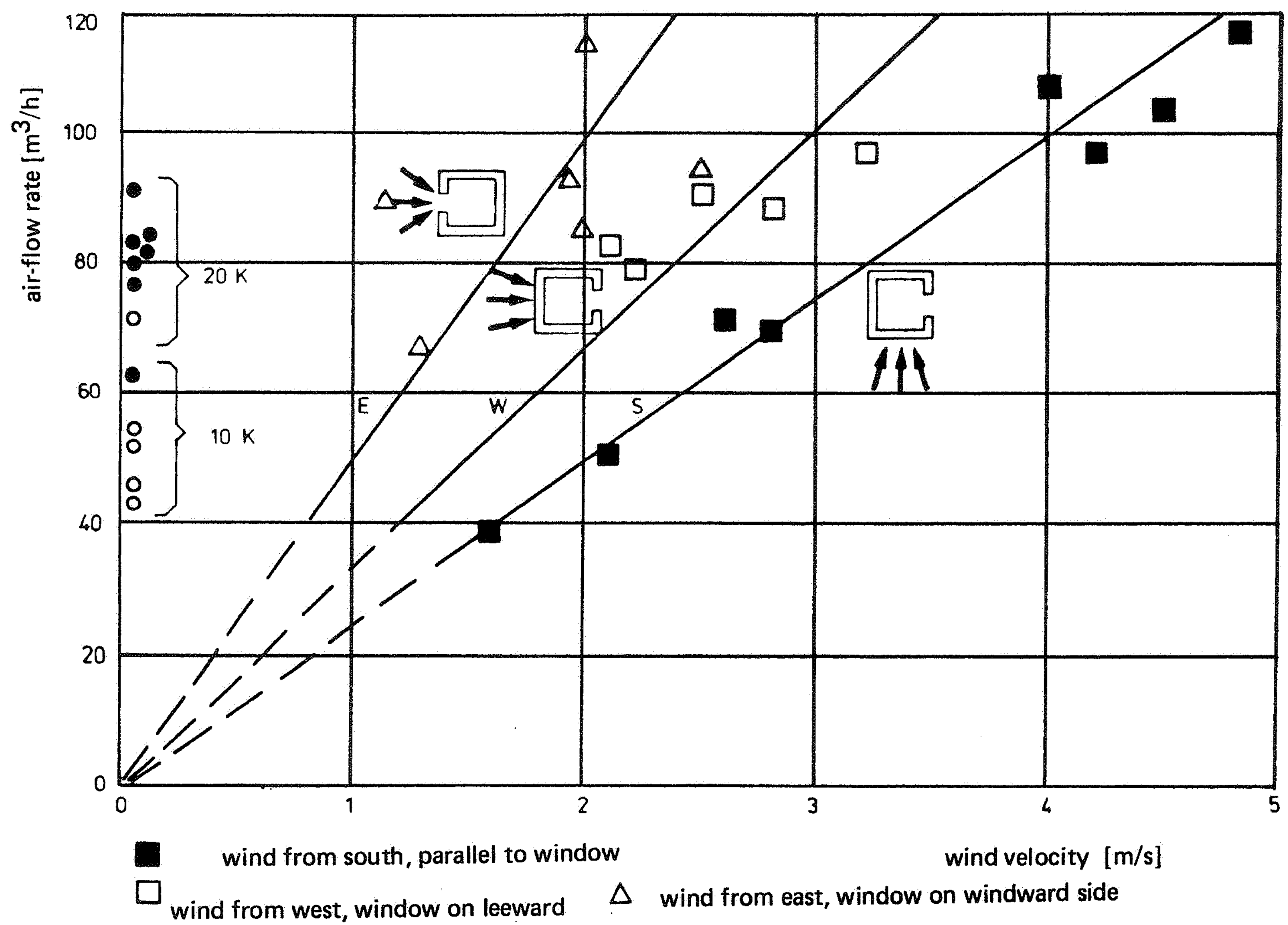


Fig. 10 : **Wind induced ventilation of balanced sash.**
Dependence on wind velocity and wind direction.
Opening width k = 6 cm, temperature difference appr. 0 K
For comparison temperature induced ventilation (at wind velocity appr. 0 m/s) is given for Δt = 10 resp. 20 K

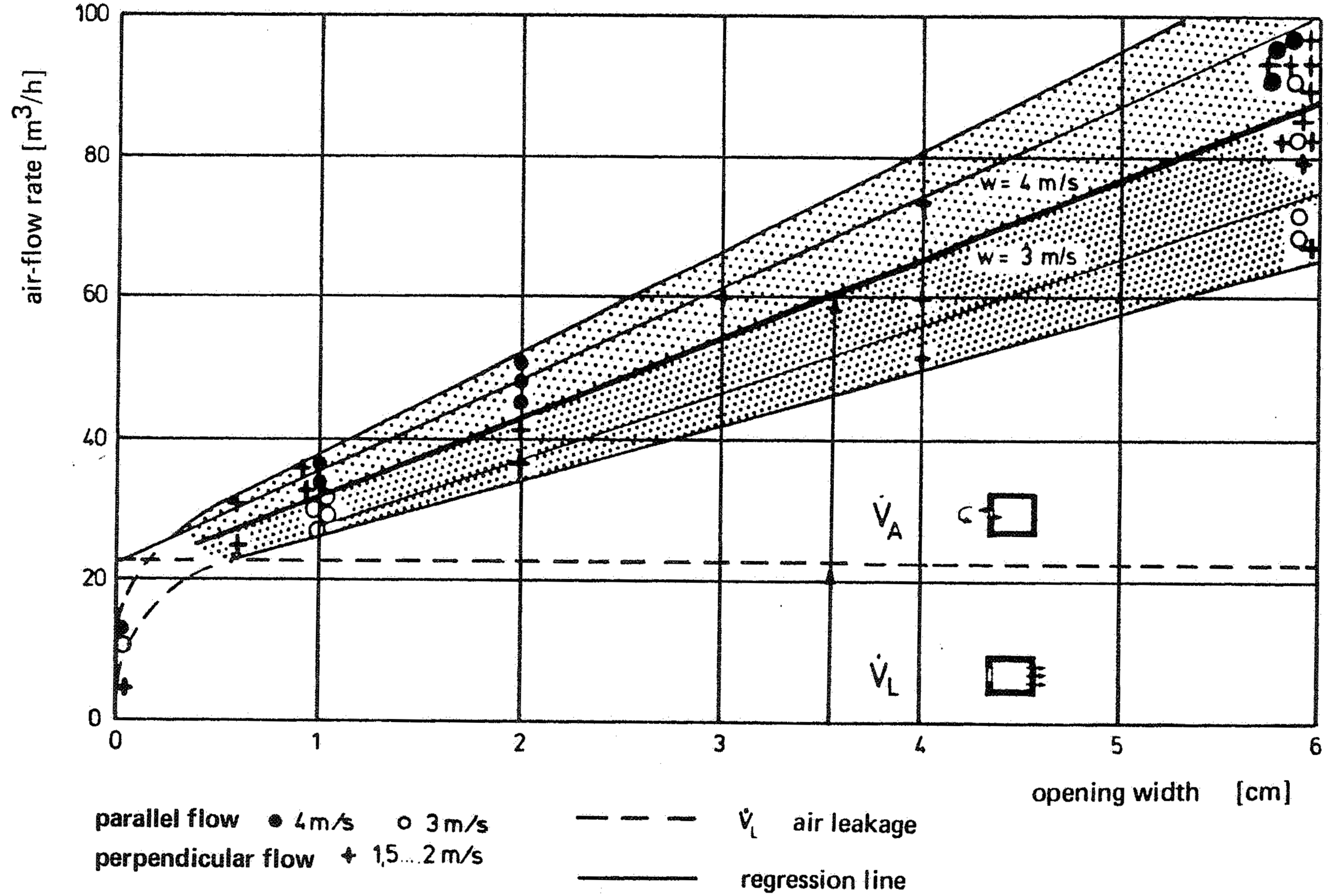
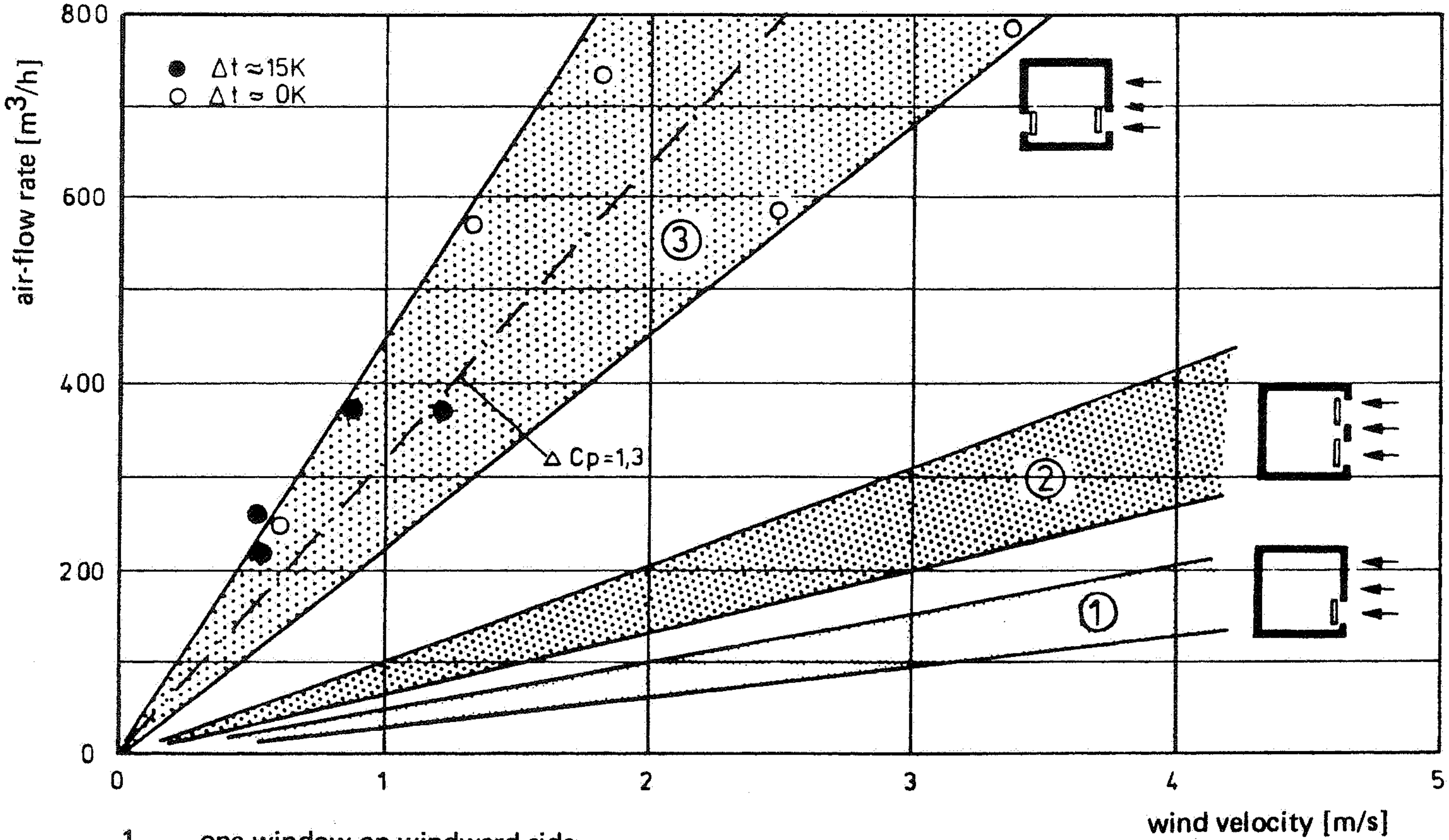


Fig. 11 : **Wind induced ventilation of balanced sash.**
Dependence on opening width at constant wind velocity.
Temperature difference Δt appr. 0 K



1 — one window on windward side

2 — two windows on windward side

3 — cross-ventilation, one window each at windward and leeward side

Fig. 12 : Wind induced cross-ventilation by two balanced sash windows at opposite sides of the test room.
For comparison data for windows installed at one side are given.
Opening width k = 6 cm in each case

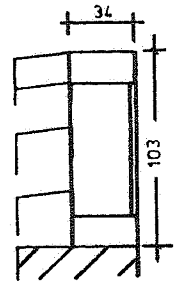
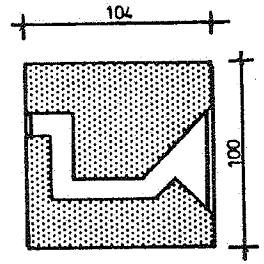
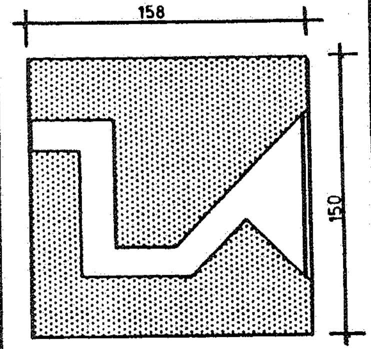
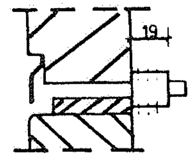
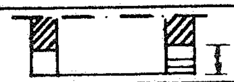
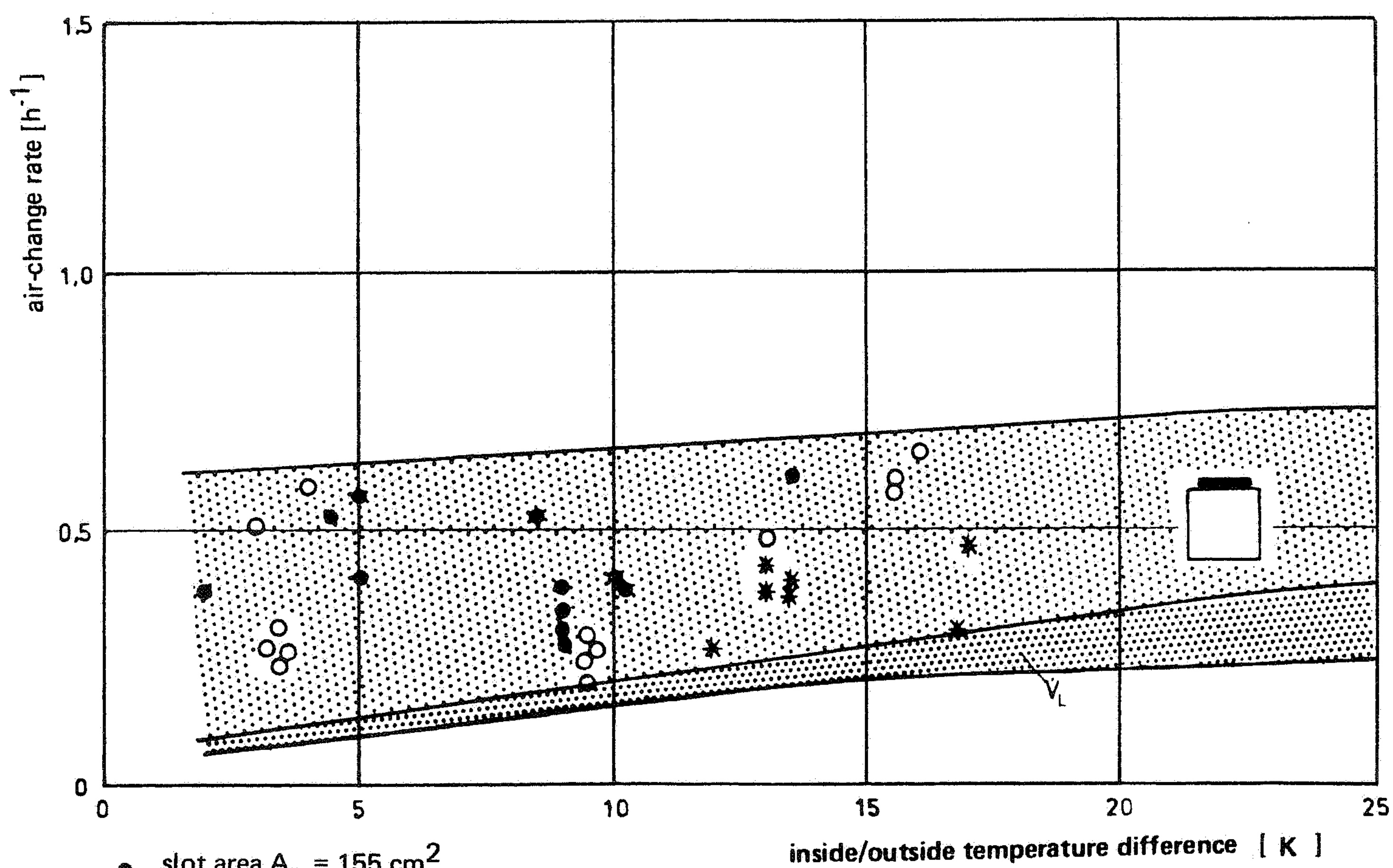
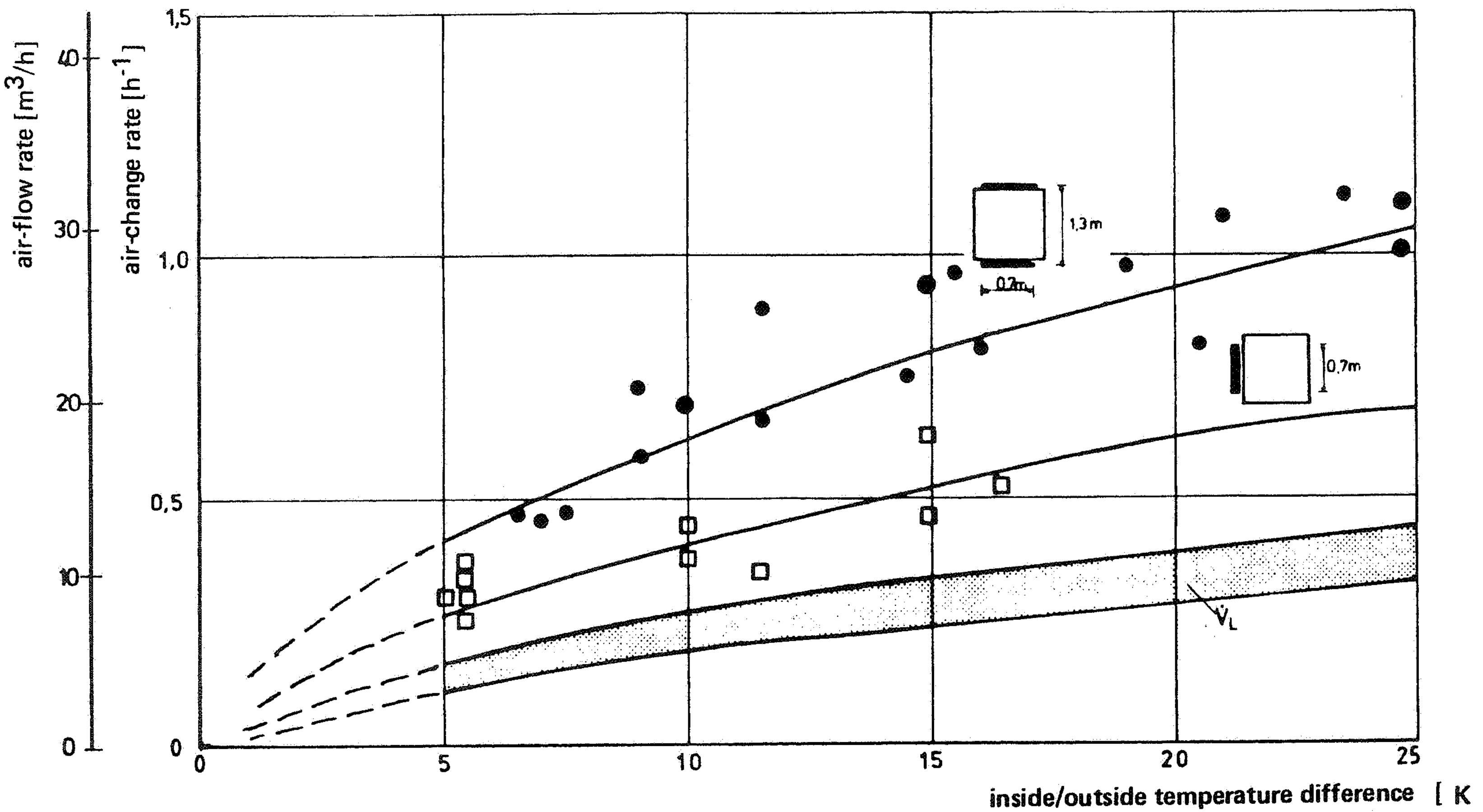
vertical cut of investigated systems				
test number	1	2	3	4
cross sectional scheme				
open flow area [cm^2]:				
outside	95	60	73	52
centre	580	79	115	52
inside	111	107	107	40

Fig. 13: **Sketch of adjustable natural ventilation systems**



● slot area A_o = 155 cm^2
○ slot area A_o = 104 cm^2
* adjustable ventilation system A_o = 23 to 53 cm^2
$\dot{V}_L$ air leakage

Fig. 14 : **One horizontally installed adjustable ventilation system or single slot of different area.**
Dependence on temperature dependence at low wind speed (below 1.5 m/s)



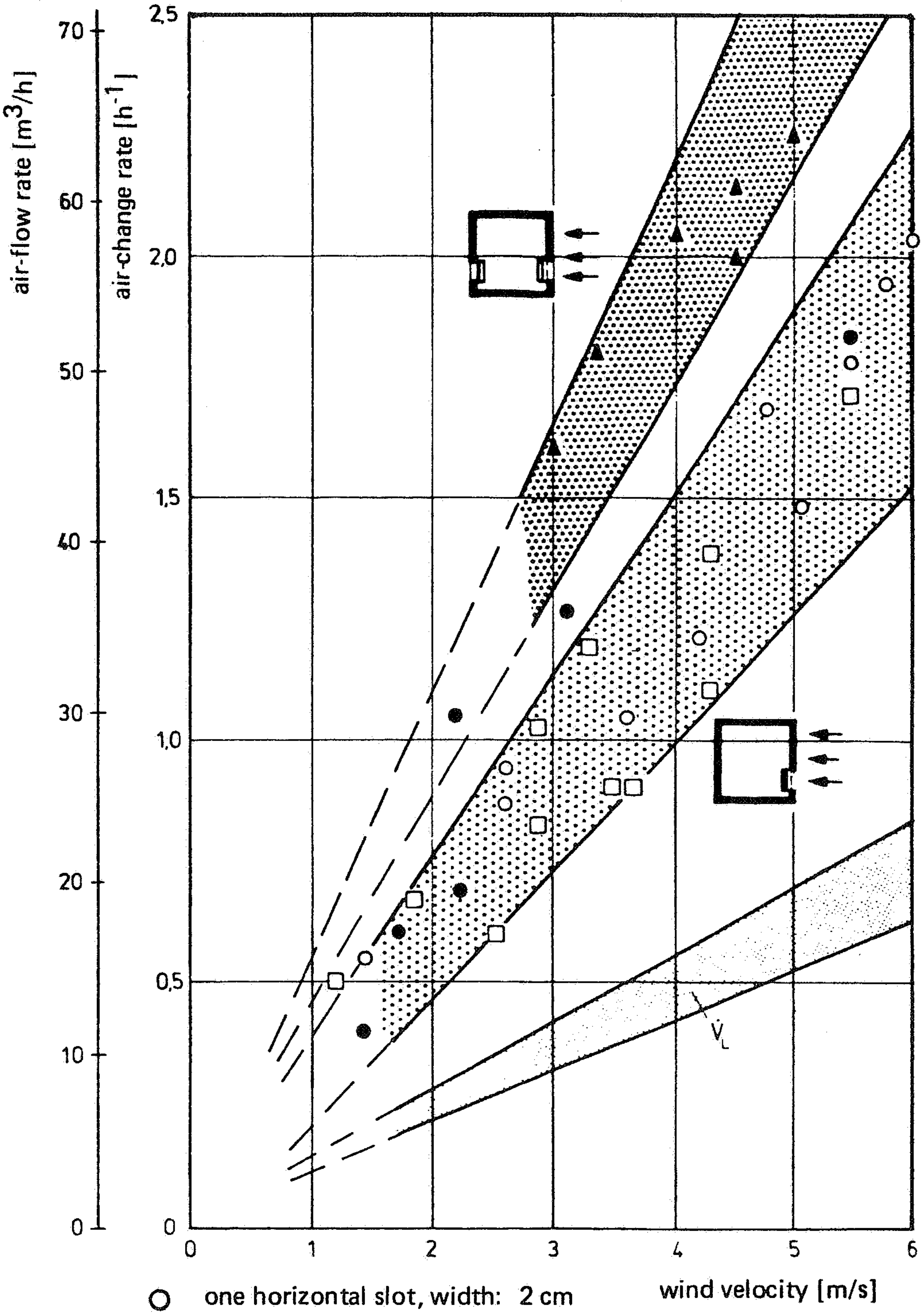
● Two horizontal openings at different height, each $A_o = 52\ cm^2$

□ One vertical slot of $A_o = 104\ cm^2$

$\dot{V}_L$ air leakage

—— theoretically calculated + air leakage

Fig. 15 : **Temperature induced ventilation of adjustable ventilation system. Wind velocity below 1.5 m/s**



○ one horizontal slot, width: 2 cm

● one vertical slot, width: 2 cm

□ two horizontal slots at different height at one side, width of each: 1 cm

△ two horizontal slots at opposite sides, width of each: 1 cm

Fig. 16 : **Influence of wind velocity of 4 different arrangements of ventilation slots. Each arrangement has the same total opening area**

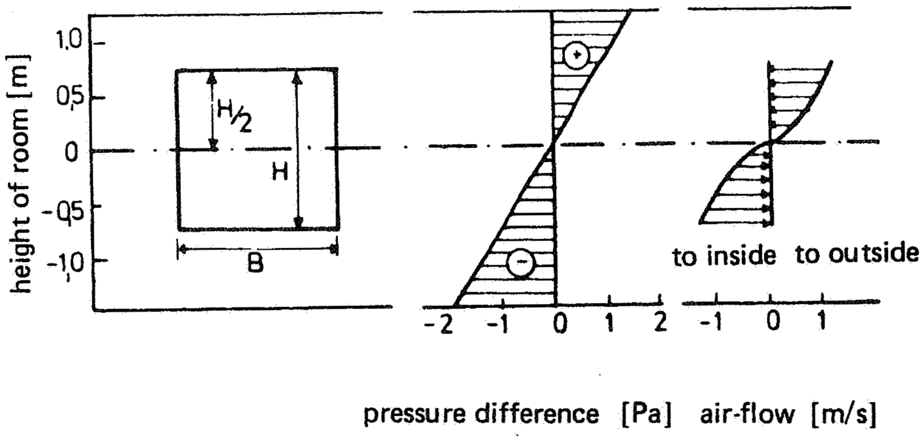


Fig. 17 : **Pressure and flow distribution at rectangular opening**

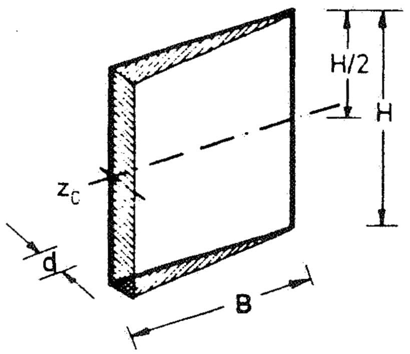


Fig. 18 : **Geometric parameters of pivoted window**

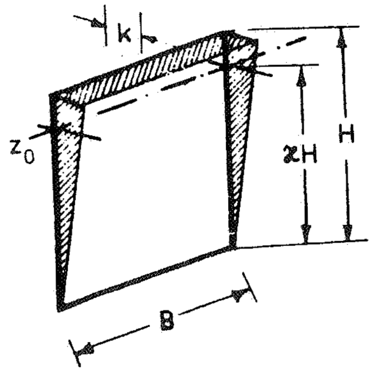


Fig. 19 : **Geometric parameters of balanced sash**

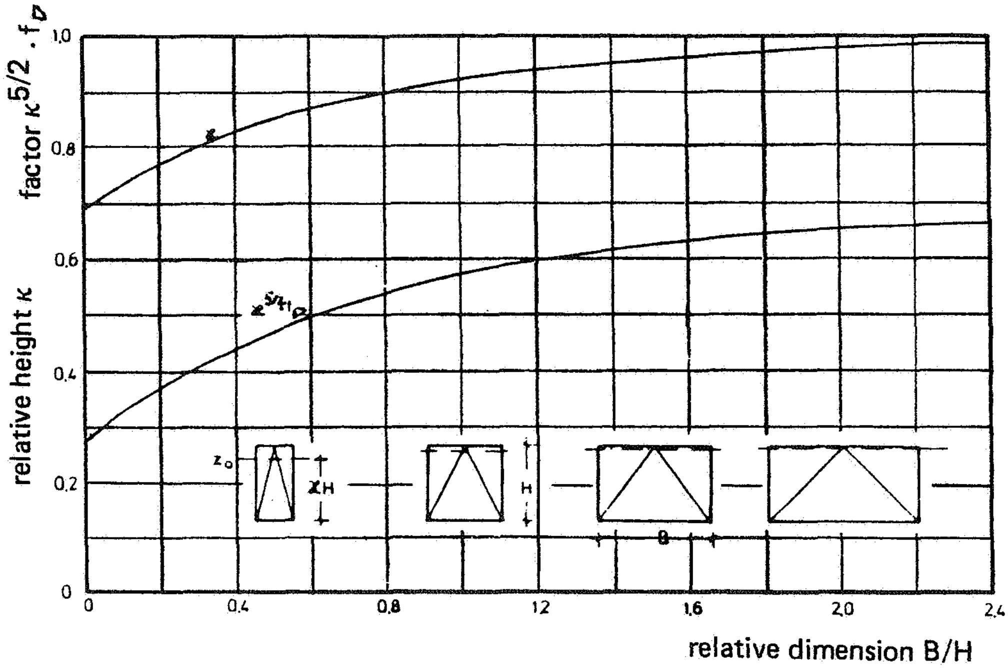


Fig. 20 : Neutral axis $\kappa \cdot$ H and factor $\kappa^{5/2} \cdot f_\nabla$ as a function of relative dimension B/H of pivoted window (f_∇ = 0.7)

ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER: B

NATURAL VENTILATION IN THE UK AND SOME CONSIDERATIONS FOR ENERGY EFFICIENT DESIGN

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1. INTRODUCTION

There are approximately 19 million dwellings in the UK and virtually all of them are naturally ventilated. Some of them are equipped with extract fans for intermittent use, but even then most of the ventilation is natural . In the past, dwellings have not been designed in detail for natural ventilation. All that has mainly been required is that they should satisfy certain very generalised specifications (e.g. the provision of openable windows), and this has proved to be a generally satisfactory procedure. However, in future low-energy dwellings excessive ventilation rates are particularly undesirable, because they negate the benefits arising from thermal insulation. On the other hand, it is equally important that ventilation rates are not reduced too far. To satisfy these two conflicting needs, means that a ventilation system should be designed much more closely than has been necessary, or possible, in the past.

Basically, the aim is to achieve an "energy-efficient" system. In the light of recent research, the present paper discusses the potential for achieving this aim by improving design procedures for natural ventilation. The paper falls into four main parts.

Section 2 considers ventilation requirements and the meaning of the term "energy-efficient" ventilation. Both of these topics are of fundamental importance to any design procedure.

Section 3 discusses natural and mechanical ventilation systems. This is done, because natural ventilation is often compared unfavourably with purpose-built mechanical systems. It is argued that such comparisons can be misleading, unless all aspects are considered.

The basic characteristics of natural ventilation are summarised in Section 4. Research in recent years has led to a considerable increase in knowledge of ventilation. This enables the main problems to be identified and indicates ways of improving design procedures.

Section 5 discusses the main aims of design and possible ways of achieving them.

Finally, there is a short summary of the main conclusions.

2. VENTILATION REQUIREMENTS

Probably the most recent concensus of views concerning ventilation requirements in the UK is incorporated in the British Standard 5925 (Ref. 1). This document gives a comprehensive summary of the reasons why ventilation is needed and describes methods for calculating ventilation requirements (i.e. air flow rates). At present, the largest requirements in dwellings will often be associated with the control of internal humidity or the dilution and removal of odours. This means that the required ventilation rates will depend on such factors as level of occupancy and domestic activities,and they will therefore change with time. This is a very important point, when defining the energy efficiency of ventilation (see below) and when considering practical design objectives.

When designing a mechanical ventilation system, one considers the requirements to be fixed values, since the purpose of current systems is to keep the whole-house ventilation rate and the room air change rates constant (some systems do have "boost" settings). Similarly when sizing permanent air vents for a natural ventilation design, one would consider only one flow rate for each room, because a vent of fixed dimensions can only be sized for one condition.

Such procedures are not really consistent with a varying ventilation requirement, but in practical terms they are probably unavoidable. However they do raise the question of whether a highly accurate design procedure is justifiable, when the actual ventilation requirements have to be expressed in a very simplified form.

This in turn raises the question as to whether more attention should be paid to the variable control of ventilation when seeking an "energy-efficient" system.

2.1. Energy-Efficient ventilation

To define the energy efficiency of a ventilation system is not easy, if only because the energy loss which one wishes to reduce is not totally involved in actually driving the ventilation process. However a loose definition is suggested in the following, because it illustrates in a concise way the basic elements of an efficient system.

A perfect system would be one in which the actual ventilation rate, R_A, is equal to the required ventilation rate, R_R, at all times i.e. the reduction of energy losses by reducing ventilation below the required levels is not desirable and therefore should be interpreted as a reduced energy efficiency, η_E. Accordingly, η_E can be loosely defined as

$$\eta_E \equiv \left[1 - \frac{\int |R_A - R_R| \cdot dt}{\int R_R \cdot dt} \right] \cdot \left(\frac{\eta_v + \epsilon}{2} \right)$$

where time integrals are evaluated over the heating season, η_v is the ventilation efficiency and ϵ is the fraction of heat loss recovered. R_A and R_R are whole-house ventilation rates, because to a first approximation the heat loss will depend on these rather than room rates.
In the above definition, the term in square brackets means that maximum energy efficiency can only be achieved when the ventilation requirements are precisely satisfied. For a mechanical system which maintains R_A at a fixed value, the term will generally be less than unity because of variability in R_R.

For a natural ventilation system, there is the additional reason that R_A will also vary, due to weather and to occupant actions (e.g. opening windows). Ideally, the control exercised by the occupant should be such as to increase η_E by adjusting R_A to be closer to R_R. If the occupant exercises no control whatsoever, then the natural system is certain to be less efficient, because $\int |R_A - R_R|$ is certain to be larger. The first term in the definition is therefore associated with control, both as a result of design (the design aim might be to make the mean values of R_A and R_R equal) and as a result of occupant action.

The second element is the ventilation efficiency, η_v. This represents the fact that the effectiveness of a given air flow rate in, say, removing odours depends on where and how the air passes through the room. Since ventilation efficiency is related to room air movements it is a very complex subject (e.g see Ref. 2). One aim of increasing η_v is to reduce R_R and methods for calculating R_R may make implicit assumptions about η_v, e.g. the assumption of a perfectly-mixed atmosphere.

The third element in energy efficiency is represented by the term ϵ. Obviously if some of the ventilation heat loss can be recovered, the energy efficiency of the system will be increased. Indeed, if the system also recovers heat from a flue, then ϵ could be greater than unity.

Of the above three elements, the first is probably the most relevant to natural ventilation design, because it is the least difficult to tackle. The second element presents much harder theoretical problems. With natural ventilation it is difficult enough to predict the air flows entering a dwelling, let alone what happens to them inside. Regarding heat recovery, it is fair to say that this has little potential, although there is some scope for it with secondary glazing (Ref. 3).

Finally, on a less technical note, any system could not be considered energy-efficient in practice unless it was also cost-effective, or unless the cost could be offset against other benefits. This is an important point when considering mechanical ventilation systems.

3. COMPARISON OF NATURAL AND MECHANICAL VENTILATION

In what follows, natural ventilation is taken to include cases where one or more individual extract fans operate intermittently. Such cases are probably fairly common in the UK and the fans can be considered as an alternative means of control to opening windows. Mechanical ventilation is taken to mean ducted systems which are intended to satisfy the requirements of the whole dwelling and which operate more or less continuously.

The main features of natural ventilation are:-

- low initial cost and maintenance costs
- mechanically simple
- widely accepted (in the UK)
- partly controllable by occupants
- unavoidable variations in whole-house rates and particularly room rates due to weather
- difficult to predict ventilation
- heat recovery not feasible

Roughly speaking the main features of mechanical ventilation are the opposite of the above. In addition, their proper operation depends on the construction of the dwelling being relatively tight. There are three basic types of mechanical systems i.e. supply, extract and balanced. The first two are the least expensive (particularly if they are part of the heating system, as in one UK warm air system) and they require less tight dwellings for proper operation (Ref. 4). However balanced systems are more easily adapted for heat recovery and allow room ventilation rates to be fixed more closely.

Purely from the viewpoint of theoretical energy-efficiency, balanced mechanical systems are more promising than natural ventilation. However their initial cost is very high and in the moderate UK climate their cost-effectiveness is doubtful (even when the expense of making the dwelling airtight is excluded), because the time taken to recover the costs of the system from the energy savings may be unacceptably long. Now, as noted in Ref.4, the basis for estimating these savings is the energy consumption of naturally ventilated dwellings. In Ref. 5 it is pointed out that with an average natural ventilation rate of 1 per hour, the balanced system does not appear to be an attractive investment. It is then suggested however, that in practice natural ventilation rates may be much larger than this due to excessive window-opening, and balanced systems may be cost-effective. This argument remains to be proven, and as will be mentioned below the experimental data on which the argument is partly based may give a pessimistic view of the effects of open windows.

Nevertheless the argument is important in the present context, because it gives a further reason for the designer to consider the control aspects of natural ventilation. In fact, if natural ventilation design can achieve average air change rates of about 1 per hour, one of the justifications for balanced mechanical systems becomes very doubtful. There are however other reasons why a mechanical system might be chosen in preference to natural ventilation. The two systems are virtually opposites and differ fundamentally in approach i.e. mechanical systems attempt to remove the need for occupant control, whereas it is implicit in natural systems. Each system has its own advantages and disadvantages, and the choice of system is likely to be decided after consideration of many different factors.

4. CHARACTERISTICS OF NATURAL VENTILATION

The inherent characteristic of natural ventilation is its variability. This has its origins in many factors, but it is convenient to summarise them here under the somewhat loose but familiar headings of leakage, weather and window-opening. Results obtained with the measurement technique ("Autovent", Ref 6)and the theoretical model ("Vent", Ref.13) developed by British gas will be used for illustration.

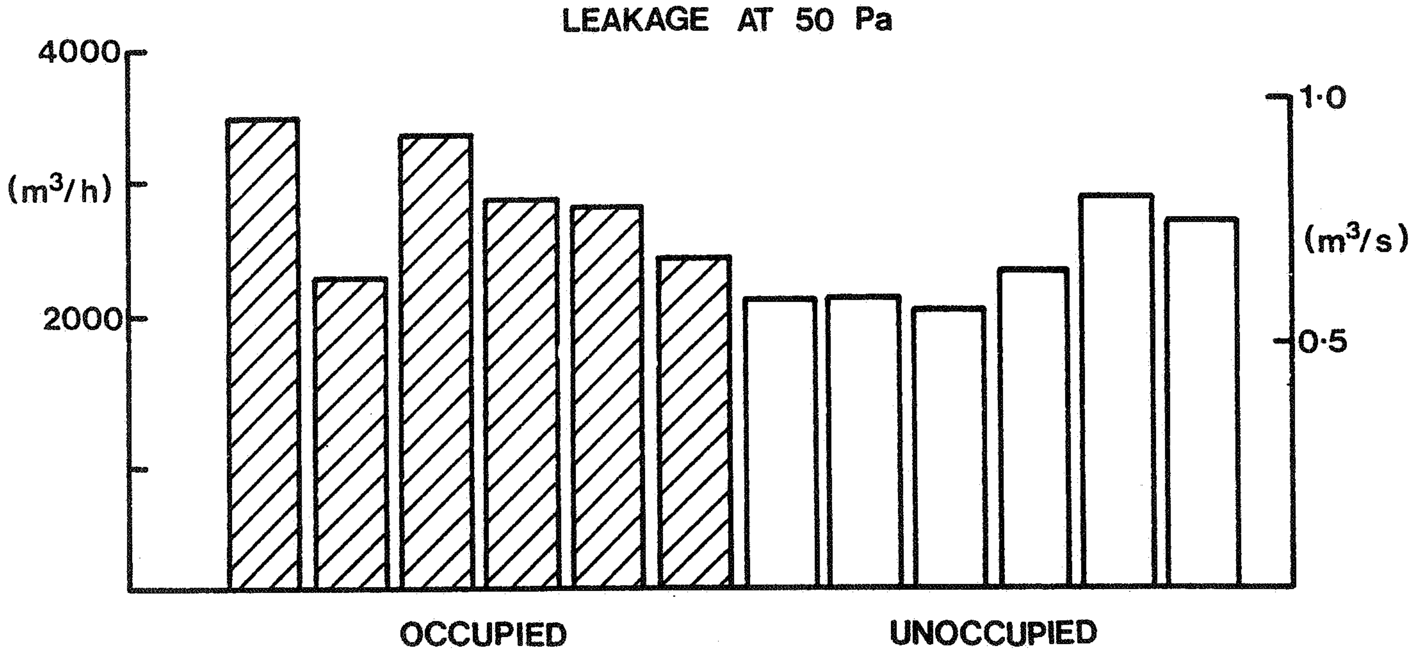
4.1 Leakage

The leakage of a dwelling (i.e. the flow rate required to pressurise the dwelling to a specified value, often 50 Pa) is likely to be one of the most important parameters in design.

The openings which contribute to the whole-house leakage can be divided into three main types (Ref. 6) - purpose-provided, component, background leakage areas. Measurements in UK dwellings (eg. Ref. 7) suggest that the third type often makes the greatest contribution, at least at high pressures. This poses problems because background openings are difficult to identify and cannot easily be controlled by design, other than by trying to eliminate them completely. One result of this is that nominally identical dwellings can have different leakages. Figure 1 illustrates this with some recent data obtained in low-energy houses.

Another feature is that the leakage of a dwelling may increase during the early part of its life, possibly by a factor of two. Thereafter smaller seasonal variations may occur.

The above characteristics are related to the construction of the dwelling and may pose severe problems to the designer. There are also some rather more fundamental problems, about which relatively little is known.



LEAKAGES OF TWELVE NOMINALLY IDENTICAL DWELLINGS

FIG. 1

First it is quite likely that the leakage of a dwelling will be used as a basis for design, by relating it to ventilation rate and weather conditions. Several calculation methods of this type already exist. However leakages are of necessity generally measured at much higher pressures than those encountered with natural ventilation. It is therefore necessary to make assumptions about low-pressure leakage behaviour, and these assumptions may be a source of considerable error. It is not inconceivable (see Ref. 8) that two dwellings with the same leakage at high pressure (50 Pa) could have leakages at 2 Pa which differ by a factor of two. High pressure leakages therefore may not be a suitable basis for design. More information about leakage characteristics over the whole pressure range is needed so that the extent of the problem can be assessed. This presupposes the existence of a suitable measurement technique which, with the possible exception of that described in Ref. 9, remains to be developed.

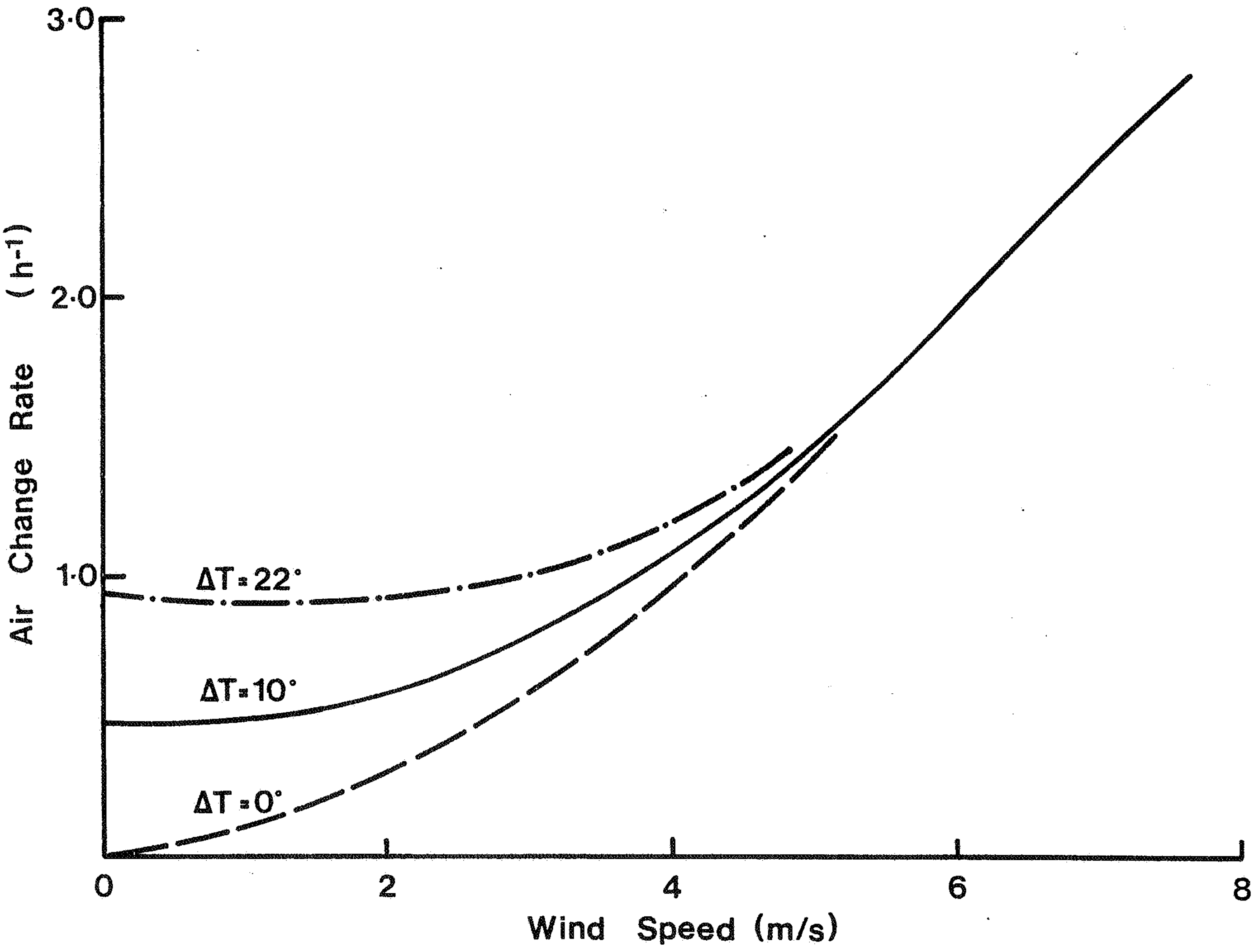
Another problem is posed by the distribution of leakage about the dwelling. Although techniques for measuring it have been developed (Ref. 6), little is known about the range of distributions likely to be encountered in practice. There is also uncertainty about how important it is. Theoretical calculations (Refs. 10 and 11) suggest that it could be significant e.g. two dwellings with identical leakages but very different distributions could have ventilation rates which differ by 50%. The influence on room rates is likely to be greater, and some experimental evidence of this can be seen in Ref. 12. Again, more information is needed about leakage distributions to assess the size of the problems. There is also a positive aspect to this, because by modifying the leakage distribution the influence of weather could be altered.

4.2 Weather

The driving forces of natural ventilation are the pressures generated by buoyancy and wind, which act on the openings distributed about the dwelling. Ventilation due to buoyancy alone is determined by the differences between internal and external temperatures. Ventilation due to wind alone is much more complex, since it depends on the speed and direction of the wind and the location and shape of the dwelling.

Design data concerning temperatures is much more readily available than it is for the wind parameters. It is fortunate therefore that buoyancy is often important in determining the ventilation of dwellings in the U.K. Not only is ventilation due to buoyancy less difficult to predict, the presence of buoyancy reduces the variability of ventilation arising from wind effects. Figure 2 illustrates these points with some predictions from our mathematical model for a detached house. Assuming that one can predict the whole-house ventilation rate with buoyancy alone (wind speed equal to zero), this prediction will be reasonably accurate for wind speeds up to about 3 m/s. Thus quite a wide range of weather conditions can be covered without any knowledge of wind parameters. This could prove to be a very valuable simplification for design purposes. Unfortunately it is likely to be less valid for terraced dwellings (where the openings are concentrated on two surfaces and high wind pressures could be encountered with winds perpendicular to the terrace), and it does not apply to room ventilation rates.

Wind effects are much more difficult to predict than buoyancy, because one needs to know the surface pressure distribution generated by the wind on the building and how this varies with wind direction. Another complicating factor is that for design purposes one needs to be able to relate the pressure distribution to a wind speed and direction for which meteorological records exist. At present such relationships have to be estimated from very limited data obtained from wind



INFLUENCE OF BUOYANCY ON WHOLE HOUSE AIR CHANGE RATES

FIG. 2

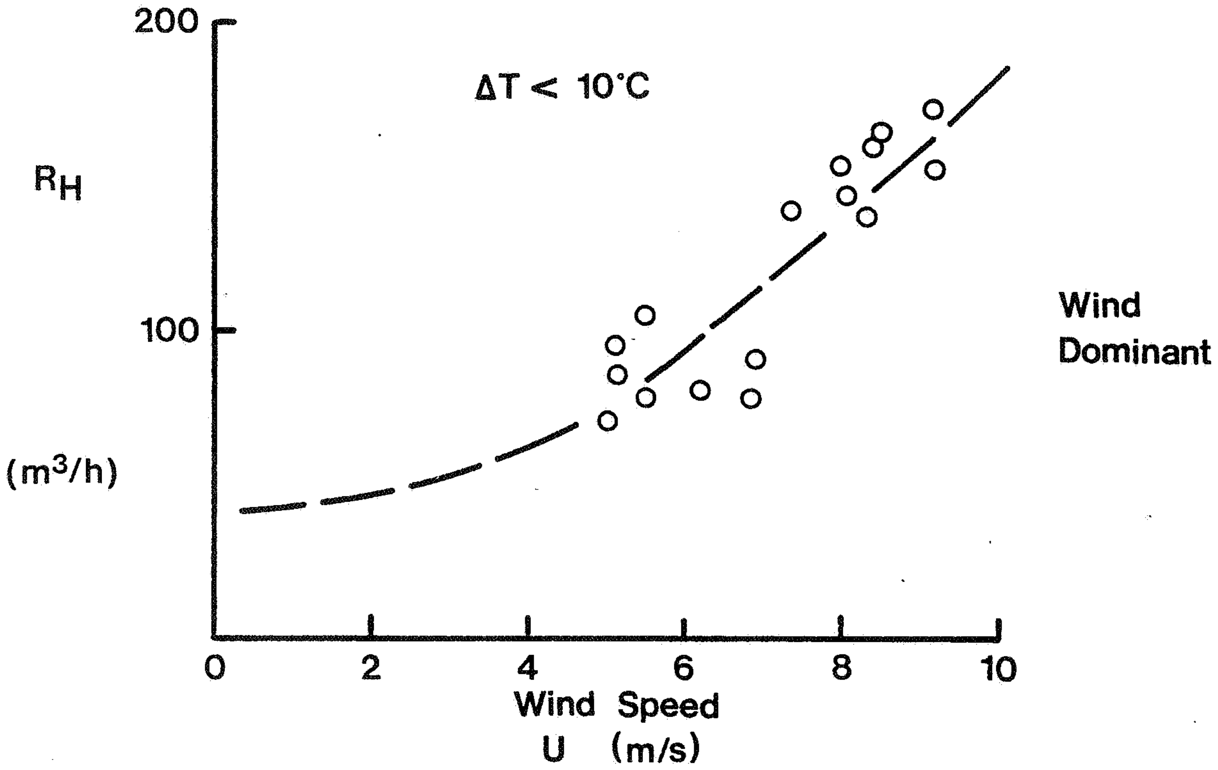
tunnel tests. There is a considerable amount of work which remains to be done on the wide range of dwelling shapes and arrangments which exist in practice. Indeed it is doubtful if all such combinations could ever be covered. For these and other reasons, there is an incentive to the designer to minimise the effects of wind.

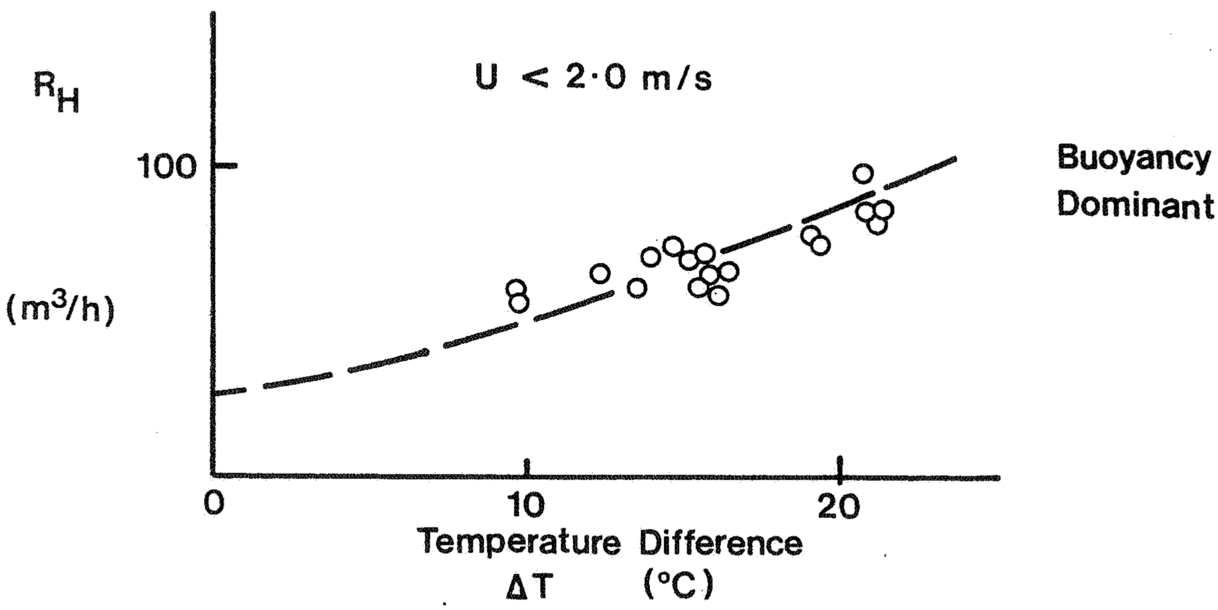
Examples of the variation of whole-house ventilation rates which arise from weather changes are shown in Figure 3 for a detached house. The two sets of results correspond to conditions when buoyancy and wind were dominant respectively. The flow rate rises from about $50m^3/h$ with a temperature difference of 9°C, to about $170m^3/h$ with a wind speed of 9 m/s. This level of variation i.e. by a factor of about three, is probably fairly typical of the effect of weather changes in the UK climate. The effect on room ventilation is more complex, as can be seen in Figure 4 which shows some of the room rates of a terraced house when the whole-house rate was nearly constant. The results in Figure 4 are plotted against wind speed to show that even when buoyancy is dominant as far as whole-house rates are concerned, the room rates can still depend on wind speed.

However to some extent, the results in Figure 4 give a pessimistic view, because they are the fresh air flow rates into the rooms. The total flow of air through the rooms (ie. the room air change rate) will be less influenced by weather.

4.3 Window-opening

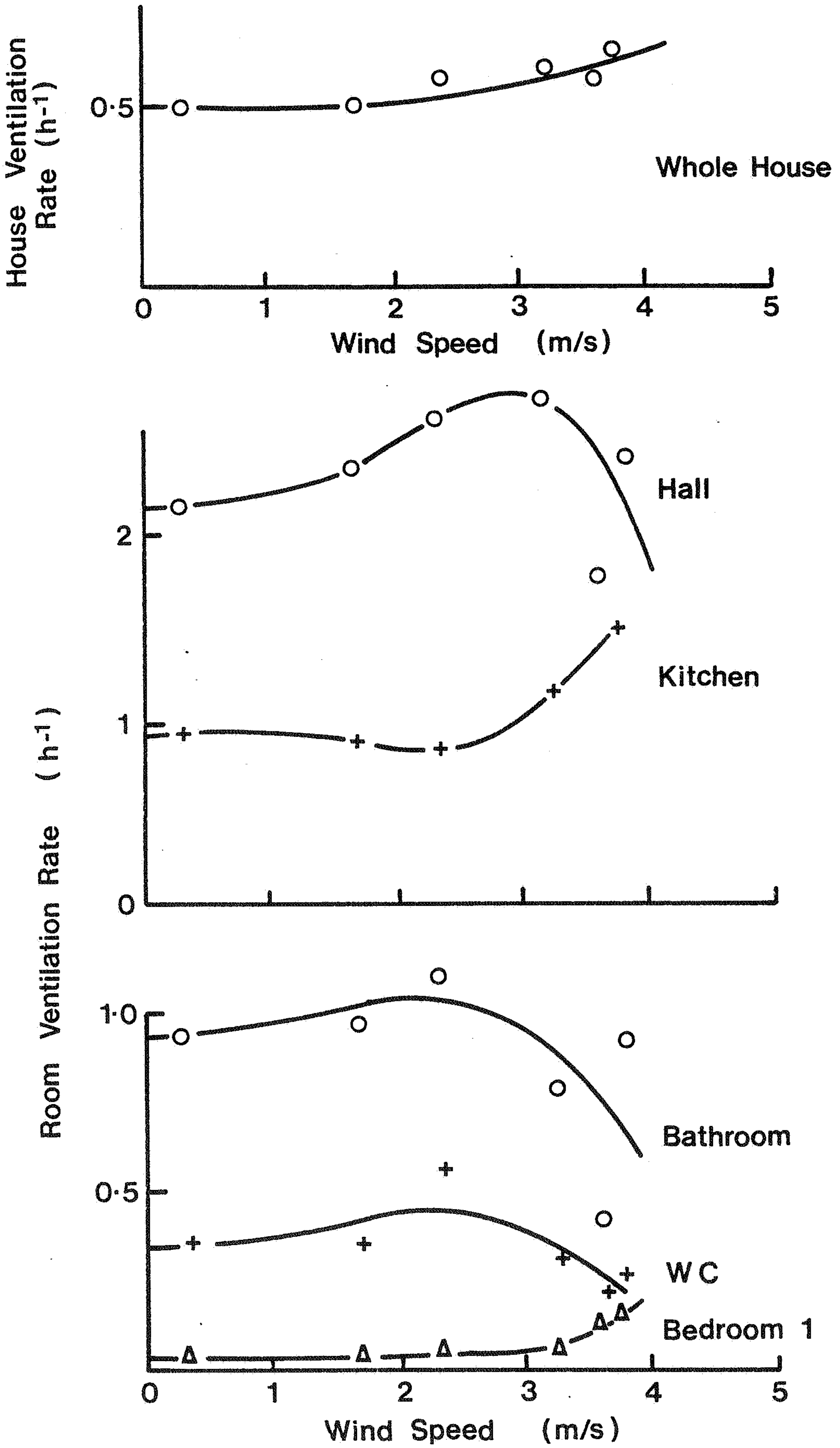
The major way (apart from an extract fan) in which occupants can exercise some control over natural ventilation is by opening and closing windows. There is evidence that open windows are fairly common in the UK(Ref.14). The reasons why they are opened and why they are closed are less well understood, but there seem to be definite associations with some weather parameters, occupancy pattern and family size (Ref.14).





MEASURED VARIATION OF HOUSE AIR CHANGE RATE R_H WITH WIND AND BUOYANCY

FIG. 3



MEASURED EFFECTS OF WIND ON WHOLE HOUSE AND ROOM VENTILATION RATES ($\Delta T = 19°C$)

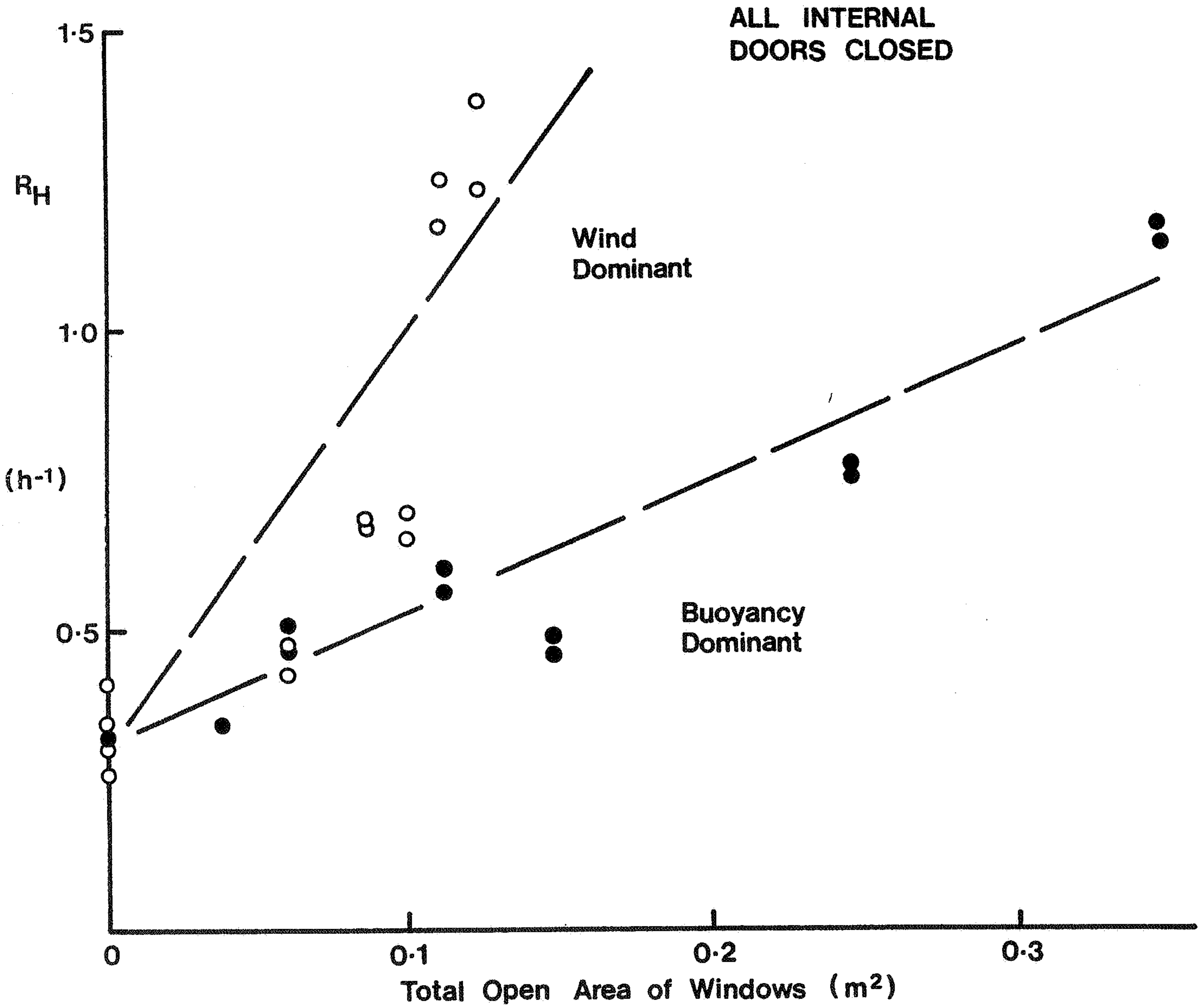
FIG. 4

The importance of window-opening to ventilation design is partly due to the very high ventilation rates which can occur. Air change rates ranging from 0.4 to 20.0 per hour are reported in Ref. 15, depending on such factors as number of open windows, their position, degree of opening and weather.

One of the criticisms of windows as a control device is that they offer only coarse control. If they are left open unnecessarily high ventilation can give rise to energy wastage. A possible way of alleviating this problem is to instal air vents which can be opened and closed, and which can be used as a fine control.

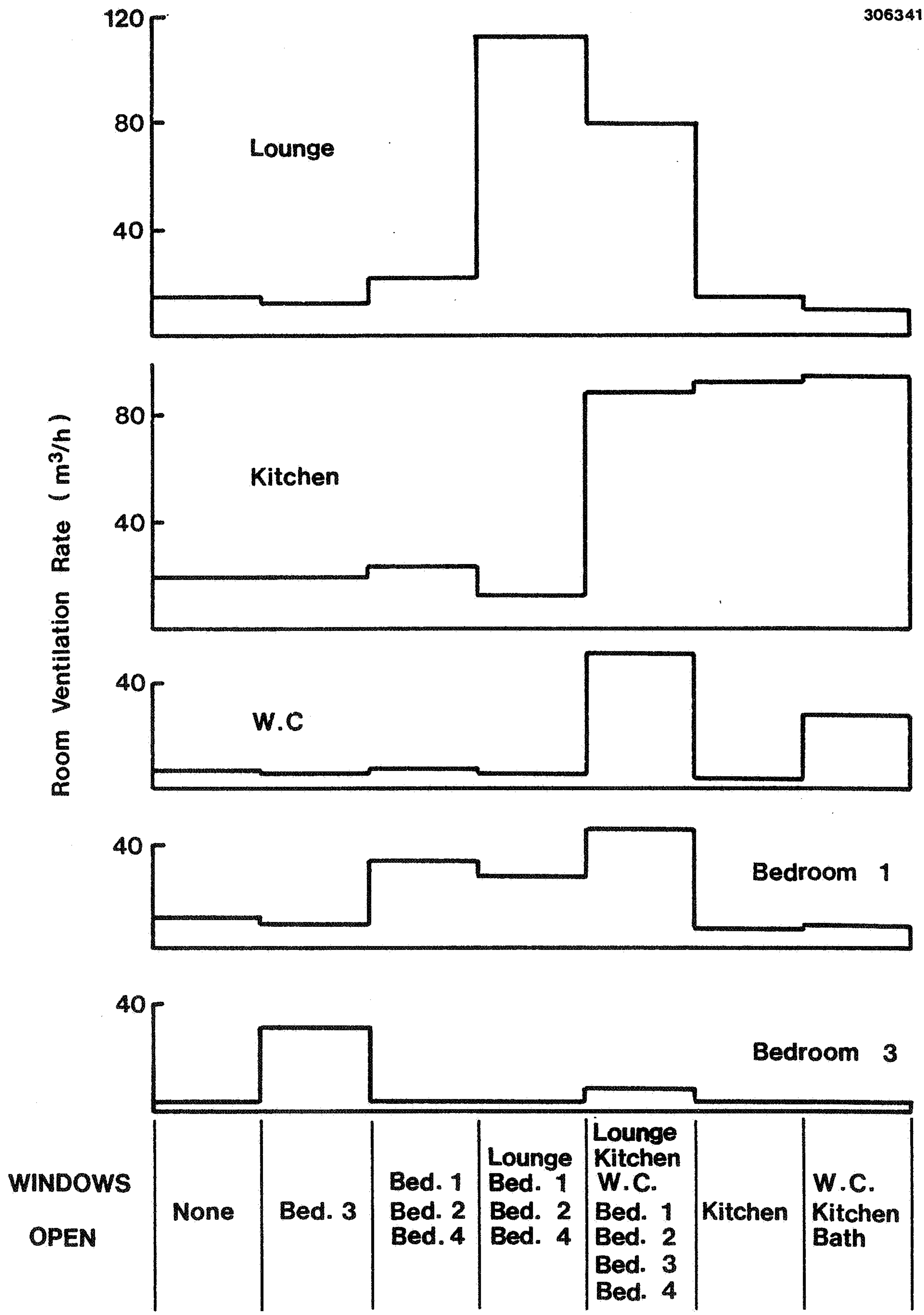
An investigation of the effects of fairly small openings has been carried out in a detached house equipped with sliding windows (they were opened to a gap of 25mm). Figure 5 shows the whole-house air change rates for a variety of window combinations and for two weather conditions where wind and buoyancy were respectively dominant. Although window-opening did cause large increases in air change rates, the values observed are at the low end of the range reported in Ref. 15. This is partly due to the small openings used in the present study. However it is probably also due to the fact that all of the internal doors were closed, whereas the data of Ref. 15 was obtained with open doors. When a room containing an open window has its internal door closed, the effect of the window will tend to be confined to the room. It will have less effect on the rest of the house when the open area of the internal door is much less than the opening in the window. Figure 6 shows some of the room ventilation rates for the buoyancy-dominant cases in Figure 5.

The measurement technique developed by British Gas can be used with doors open or closed, and Figure 7 shows some results which illustrate the effects of the doors. The tests were carried out in a terraced house with an upstairs window opened to a gap of about 75mm. For one set of results all doors were closed, and for the other two doors were opened (one being in the room with the open window). The results indicate that data obtained with



EFFECT OF WINDOW OPENING ON HOUSE AIR CHANGE RATE
R_H FOR TWO WEATHER CONDITIONS

FIG. 5



EFFECT ON ROOM VENTILATION RATES OF SMALL WINDOW OPENINGS. BUOYANCY DOMINANT

FIG. 6

all doors open gives a pessimistic view of the effects of window-opening. In practice the door to the room containing the open window is equally likely to be closed. In which case the effect of the window would be to increase the air change rate of the room by a large factor, but with a relatively modest increase to the whole-house rate.

5. NATURAL VENTILATION DESIGN

As noted in Section 2, the main purpose of natural ventilation design is likely to be to maximise the term in square brackets in equation 1. This basically means that the design process should aim: -

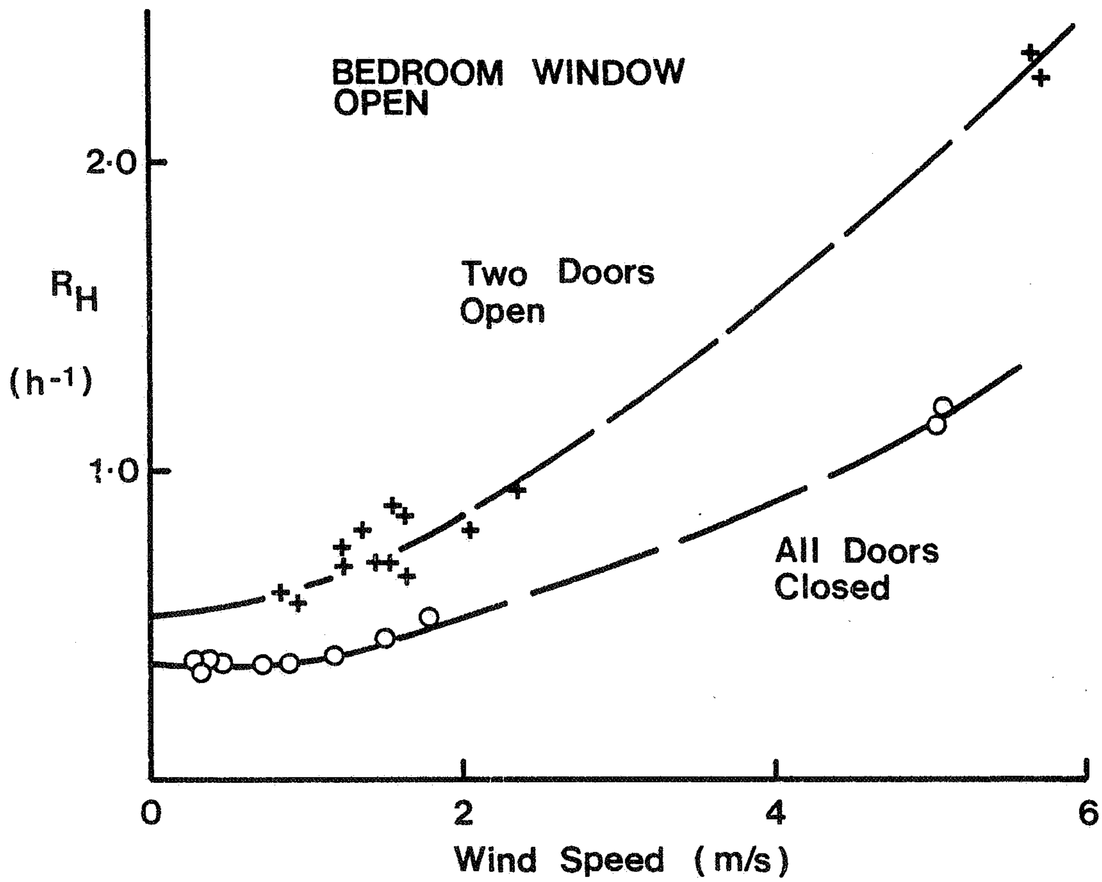
- to ensure a basic level of ventilation under specified weather and house conditions
- to minimise the variations due to weather
- improve occupant control

These three aims can be dealt with under the headings used in the previous Section.

5.1. Leakage

The achievement of a basic level of ventilation is closely connected to the achievement of a known leakage, but the discussion of leakage in Section 4.1 was basically a catalogue of problems for the designer.

In theory all of these problems can be overcome if the dwelling can be constructed such that the leakage due to component and background openings is negligible. The desired leakage and leakage distribution can then be achieved with the installation of permanent air vents. The low-pressure leakage characteristics of these can be measured in the laboratory, thus enabling ventilation to be more reliably predicted. Basically what is required is an airtight structure. Techniques for achieving this have been developed in Sweden (Ref. 16), because airtight dwellings are needed for proper operation of balanced mechanical systems.



MEASURED EFFECT OF INTERNAL DOORS ON HOUSE AIR CHANGE RATE WITH ONE WINDOW OPEN

FIG. 7

However, there are arguments against such a radical approach. It would require the adoption of new and probably more costly construction techniques, which might be difficult to justify on the grounds of theoretical improvements to ventilation and/or cost-effectiveness, particularly when it is remembered that window-opening by the occupant can substantially increase leakage. Moreover, the concept of airtight construction for dwellings may be questionable from the environmental and safety viewpoints, because air vents can be sealed (and mechanical systems can be switched off).

An alternative approach is to accept some leakage in the construction, but to ensure that it lies within certain limits. Providing it is not too large, background leakage has some desirable features i.e. it offers a base level of ventilation which it is difficult to reduce, and air which enters is generally well distributed and less likely to cause draughts. Adoption of this approach implies the adoption of a leakage standard and some means of monitoring it. Assumptions would need to be made about the characteristics of the background leakage. The level of uncertainties introduced by these assumptions would depend on the extent to which the leakage was increased by the installation of permanent vents.

Neither of the above alternatives has been adopted in the UK. However if the basic ventilation level is to be included as part of the design, one or other alternative would probably be necessary.

5.2 Weather

A possible way of reducing variations due to weather is to minimise the effects of wind. This might be done by maximising the effects of buoyancy, which would be assisted by maximising the heights between purpose-provided openings i.e. low-level vents on the ground floor, high-level vents on the upper floor. The adoption of vertical ventilation ducts, as used in some European countries, might also be considered. A more radical possibility is the use of sheltering (e.g. by trees) to reduce the pressures generated by the wind.

Another possibility, which would act on both buoyancy and wind effects, is the use of vents which in some way prevent high flow rates. Such vents are sometimes described as "constant-flow" vents. Before considering their use, however, one would need to be assured of their long-term reliability.

There are other possibilities connected with the siting of vents in relation to prevailing wind directions. Terraced houses with only two exposed surfaces obviously present a problem here, and perhaps consideration could be given to the alignment of the terrace relative to prevailing winds.

5.3. Occupant Control

One way in which occupant control might be improved is to install variable vents which offer a finer control than that normally associated with windows.

Extract fans also offer better control than windows, particularly when high ventilation rates are required. They have a fixed flow direction and they are less likely to be left operating, especially when they switch off automatically.

Both of the above options are already in use in the UK, and so it should be possible to determine their effectiveness.

A more radical option is the use of tight internal doors (perhaps self-closing) on bathroom and toilet. These rooms could then be well-ventilated with minimal spread of odours and moisture to other parts of the dwelling. This option might also be considered for other rooms, to reduce the undesirable aspects of window-opening.

6. CONCLUSIONS

Design techniques for natural ventilation should aim to (a) achieve a basic level of ventilation under specific conditions, (b) minimise variations due to weather and (c) improve the potential for occupant control. Several possibilities have been outlined in this paper which offer improvements in each of these areas.

Further research is particularly required to determine the accuracy with which (a) can be achieved, even though ventilation requirements are complex and for design purposes they are often expressed in a very simplified form.

A perfect energy-efficient system would be one which satisfied the ventilation requirements at all times. Natural ventilation systems can never achieve this ideal, because random variations occur due to weather and because occupant control is not precise. However, by paying attention to the aims (b) and (c) above, it should be possible to make significant design improvements in these areas.

Neither do current mechanical ventilation systems satisfy the above ideal. They are theoretically more energy-efficient, but in practice this theoretical potential may be undermined by the fact that such systems are not cost-effective. The argument that mechanical systems with heat recovery are cost-effective, because natural ventilation gives excessive energy consumption due to window opening, remains to be proven. The high air change rates sometimes associated with open windows may be overestimates, because internal doors are not always open.

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ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

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PAPER C

VENTILATION HEAT LOSS IN A DETACHED ONE FAMILY HOUSE

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SUMMARY

For optimum building design it is of importance to investigate the comfort and the energy conservation obtained with different types of ventilation systems and levels of airtightness of buildings. This could be achieved by aid of computer models based on full-scale and model measurements.

In order to obtain experimental data as input data to such a computer model, an experimental, detached one-family house has been built near to Gothenburg on the Swedish west coast. The house is inhabited and has built-in facilities to change the air tightness level and distribution by specially designed leaking panels. It is also possible to alter the flow rates, using one of three possibilities regarding ventilation; natural ventilation, mechanical exhaust ventilation and mechanical supply and exhaust ventilation with heat recovery.

The house, moreover, is equipped with a pressure scanner and plastic tubes connected to some 250 pressure taps, distributed around the perimeter and in wall and roof cavities. Data from the pressure scanner are fed into a computer system together with continuous data concerning wind speed, wind direction, temperature and tracer gas concentration.

This paper outlines the research program and describes the instrumentation and some features of the house.

1. INTRODUCTION

In order to minimize the ventilation heat loss but retain an acceptable indoor air quality, the Swedish Building Code of 1975 contains strict rules governing the various kinds of ventilation systems and the levels of air-tightness of buildings. There exists, however, very little basic data to justify the rules about air-tightness and the levels are not related to the types of ventilation systems chosen.

The code has had a very rapid impact on building practice. Clearly a future revision of the code as regards ventilation and air-tightness should be based on a careful study of cost effectiveness, durability and the inhabitants' comfort and health. Such a study could be based on computer models of infiltration, verified by model and full-scale measurements.

The interaction between the climate, the building and its services and the occupants is very complex. In full-scale measurements the number of parameters is large, some are difficult and expensive to monitor and many are difficult to control.

It was judged to be most expedient to divide our work on air infiltration into two different projects as follows.

1) Investigations of a few,recently built, detached, one-family houses. Measurements of climate parameters, wind pressures, ventilation and air infiltration with a limited number (≈100) of removable sensors and over a limited time (1 - 3 months).
2) Investigation of a single experimental house with built-in facilities for changing the air-tightness level, leakage distribution, type of ventilation system and flow rates. Measurements as in 1) but with a greater number (≈300) of built-in sensors and over a longer time (≈1 year).

Here we shall discuss the second project. As no measurement data are yet available, the paper will be restricted to a discussion about the purpose and planning of the project and a brief description of the experimental house and its instrumentation.

2. THE PURPOSE AND PLANNING OF THE PROJECT

The main purpose of the project is to investigate how the total ventilation rate and the ventilation heat loss in one-family houses depend on certain important parameters. The investigation is restricted to one experimental house, in which some house parameters can be altered. These include :

- type of ventilation system, i.e. natural ventilation, mechanical ventilation, or mechanical exhaust and supply ventilation with heat recovery,
- mechanical ventilation flows,
- air-tightness and leakage distribution.

Local climatic data for one year will form the basis of the investigation. By means of a computerized data aquisition system, hourly values of wind speed, wind direction and temperature will be collected. A change in the house parameters is equivalent to the creation of a different house set-up. Spread over the year, under different weather conditions, a certain house set-up will be measured intensively during periods of a couple of hours. These measurements will include measurements of wind pressure around the house perimeter and in wall and roof cavities, thermal stack effect, ventilation duct flow and total infiltration rate.

The corresponding ventilation heat loss will be computed for each measuring period as a function of the house set-up and the weather conditions. For each house set-up the total ventilation heat loss during one year is estimated by taking the individual heat loss values and weighting them by a time coefficient, corresponding to the total yearly duration of the pertinent weather conditions. In addition to average values of heat loss, variance of the ventilation rate will also be calculated. These values will be able to be compared and conclusions drawn concerning the merits of different house set-ups with respect to energy conservation, economy, and comfort.

Each measuring period will provide several thousand primary values. A large number of such measuring periods will be needed in order to accomplish the previously described analysis. A very large amount of data will thus become available for testing mathematical models of air infiltration.

3. THE EXPERIMENTAL HOUSE

3.1 The Topography

The house is built on the Swedish west coast, 17 km south of Gothenburg centre and 3½ km from the coast. Except for vegetation the area is rather exposed, the prevalent wind direction being south-west. It is situated on a high plateau, 80 m above sea-level, figure 1. The vegetation is not cultivated and consists of a mixture of deciduous (mostly birches) and non-deciduous trees. The house stands isolated in a clearing and is several hundred meters from the nearest neighbour.

3.2 A general description of the house

The house is a 1½ storey timber framed house, erected above a concrete structural floor. This is a very usual and economical house type in Sweden. The house also has two common features, namely a dormer window and a gable balcony. The balcony is visible in figure 2. The walls are cladded with cover boardings and the roof with concrete tiles. A cellar and an adjoining garage are built into the ground, with a low slope towards the south. The cellar will be sealed from the house during the experiments.

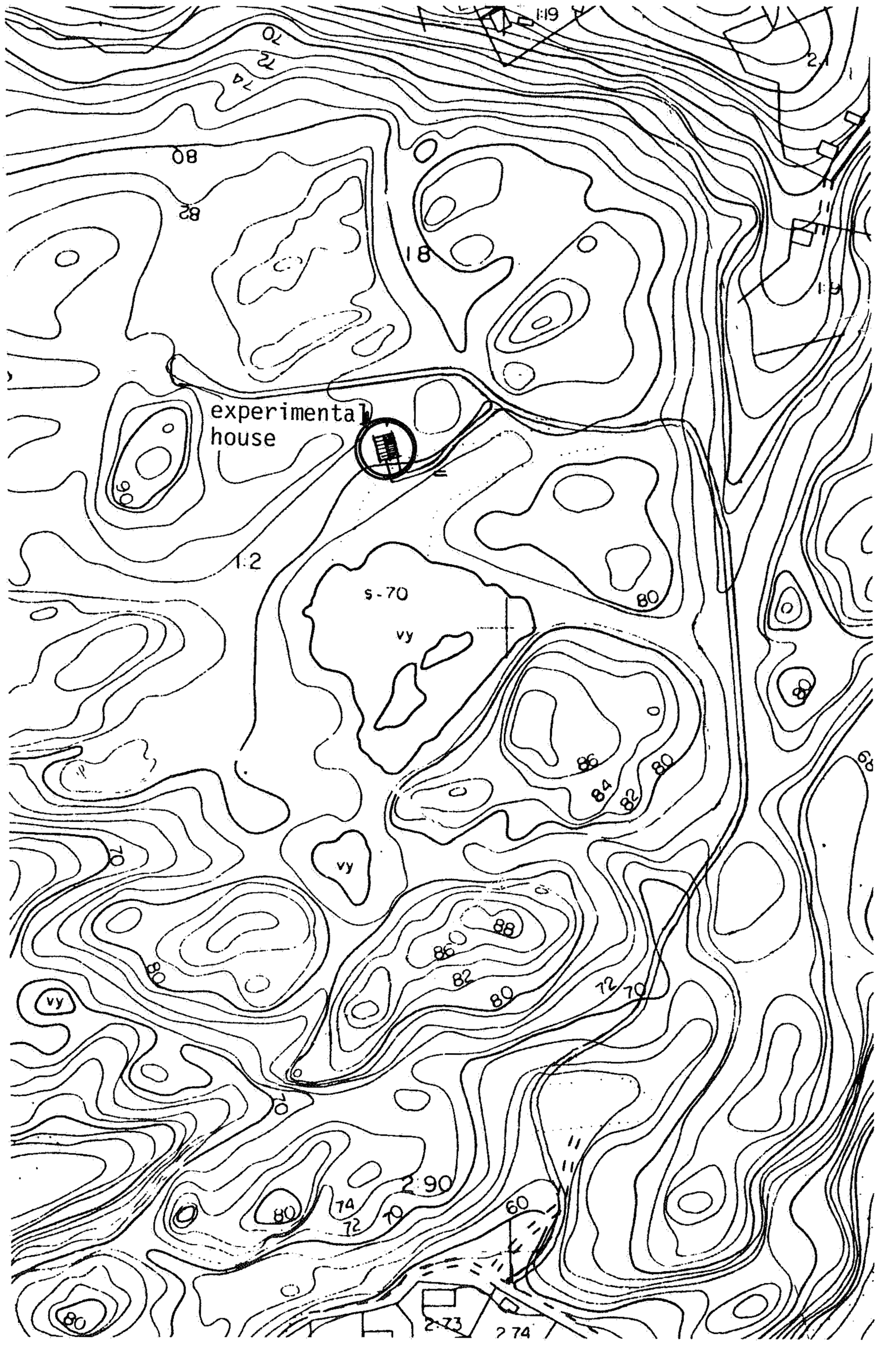


Figure 1. Topography. Map scale 1:4000 with 2 m contours.

Figure 2. The experimental house as seen from WSW.

The house has a high thermal insulation standard due to triple glazing and 265 mm of Rockwool in the walls and roof, cf. the cross-section in figure 3. The heating system consists of a heat pump with brine pipes in a small nearby lake. The heat pump provides all the domestic hot water and the space heating, the latter consisting of plastic pipes in the concrete cellar floor and in the false ceilings in the ground and upper storeys. The performance of the heating system is monitored as part of a separate project, which does share the data aquisition system and adds a further 100 sensors to it.

The house is privately owned and inhabited by the author and his family. Normal building costs are being met in the usual way through a bank and a building society. The additional costs for the experimental parts of the building are covered by a scheme administered by the National Swedish Council for Building Research. Under this Energy Experimental House Scheme, interest and repayment free loans are provided during the time the experiments are made. Thereafter part of the loan must be paid back by the house owner, in accordance with the true benefits gained from the investment made in experimental energy-saving equipment.

3.3 Air-tightness

Much effort has been made to make the house as air-tight as possible. The air-tightness is mainly ensured by a special long-life 0.2 mm thick plastic sheeting. It has been placed about 6 cm into the wall and roof, as seen in figure 3, thus leaving space for electrical wiring etc. The sheets are joined together with plastic tape. This was shown to be a mistake. We found no tape that could

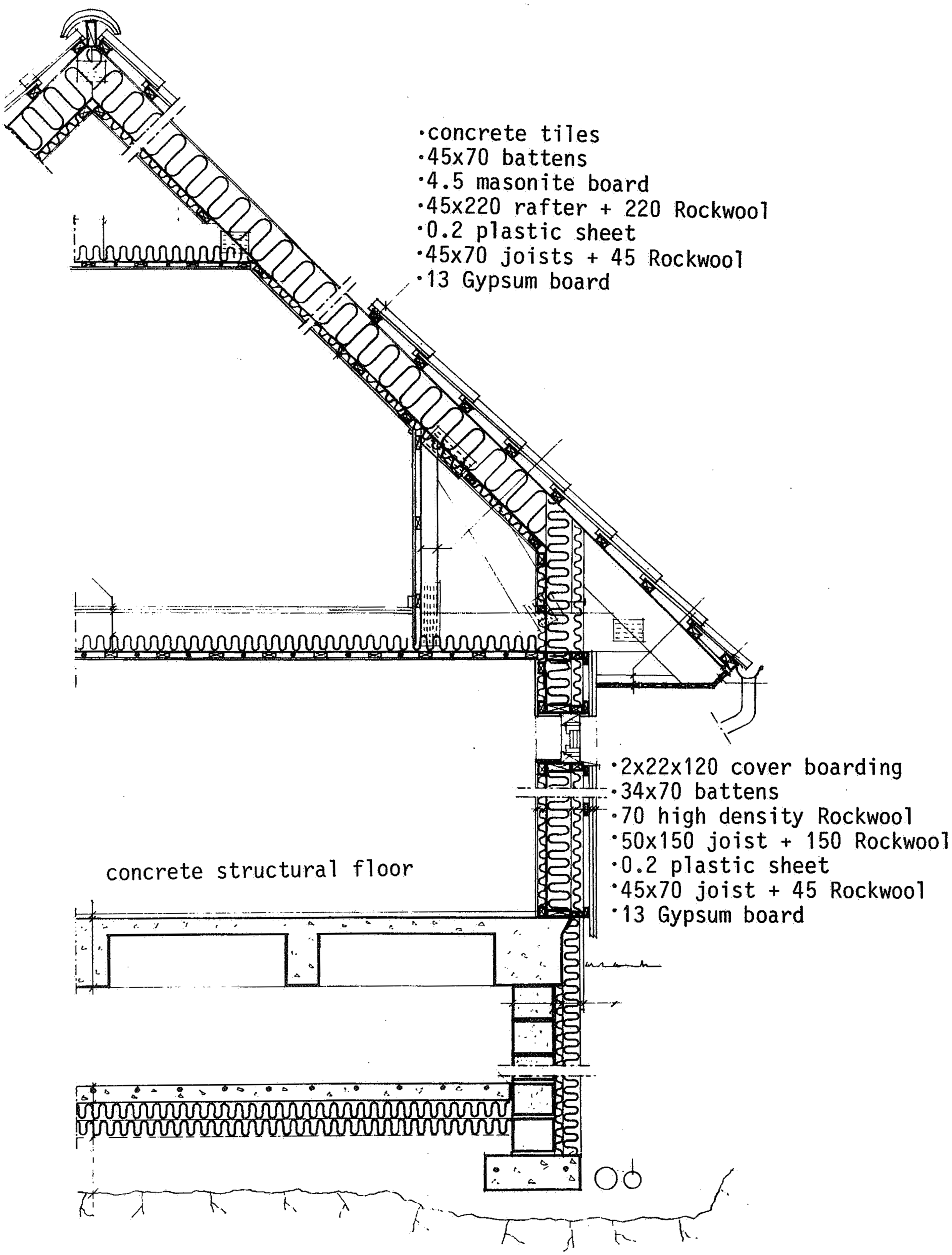


Figure 3. Cross section.

give satisfactory service when used by ordinary workmen. As the plastic sheets were left exposed for rather a long time during construction work, the tape could be seen to loosen, a process which seemed to be caused by stress introduced during mounting. Only by extreme care in avoiding this stress, could the tape be made to stay in position. A much more satisfactory performance was obtained by tape on a paper base, coated by melting glue. It was put in place between plastic sheets and protruding joists and timber frame in window openings, by means of an ordinary hot iron.

All doors, windows and airing panels are of good quality and were air-tightness tested in our laboratory prior to mounting. They all fulfilled the requirements in the building code with an air-leakage well below 1.7 $m^3/h.m^2$ at 50 Pa. The space between these elements and the timber frame were foamed using I-component polyurethane foam.

The air-tightness level of the house and leakage distribution can be altered by means of the nine airing panels, which are situated on all sides of the building. Their normal, air-tight doors can easily be replaced by special leakage panels.

3.4 Ventilation systems

The mechanical ventilation is provided by an ordinary supply and exhaust ventilation system with heat recovery. The heat exchanger is of the regenerative type, working with alternating (1 minute) air flow directions in two duct elements filled with corrugated aluminium sheets. This system was chosen as it is claimed to give high thermal efficiency and no extra heat is needed for de-icing in winter time. The working principle makes the measurements more complicated, however. Duct flows can be altered by restrictions in the ventilation ducts and by regulating the fan speeds by means of variable transformers. By sealing the supply air duct, the system is changed to an ordinary mechanical exhaust air system.

The natural ventilation system consists of ducts separated from the mechanical ventilation system. It conforms to the regulations in the Swedish Building Code, with the exception that all ducts are brought together into one in the attic, where the flow rate is measured.

4. INSTRUMENTATION

4.1 Data aquisistion system

The data aquisition system is placed in a special room in the cellar and consists of the following main units :

- desk computer, Hewlett Packard 9835A with 49 kbytes memory,
- digital voltmeter, Solatron 7055,
- analogue scanner, Solatron, 200 channels

- pulse counter, Meteb, 100 channels
- solenoid valve scanner , purpose built, 276 channels, with Setra differential pressure transducer, ± 100 Pa range
- printer, Anadex.

The computer and the instruments communicate via the HP-IB bus. For ease of operation the system needs to be expanded to include extra computer memory and a disk drive. A plotter would provide means for real time analysis and checking.

4.2 Weather monitoring mast

A weather monitoring mast is placed on a low rock, 25m from the house, see figure 4. The mast consists of a 16m high steel flagpole. The following units are are mounted on the flagpole, with heights measured from the foot of the pole :
- cup anemometers, Vaisala , at heights of 3.5m (at the same height as the ridge of the house), 10m and 16m,
- wind vane, Thiess, height 16.5m,
- shielded temperature sensors, Pt100 + thermocouples, heights 2m and 15m,
- static pressure probe, double disk type, height 15.5m.

Thermocouples are placed along the plastic tube from the static probe to the valve scanner in order to provide information for stack effect compensation.

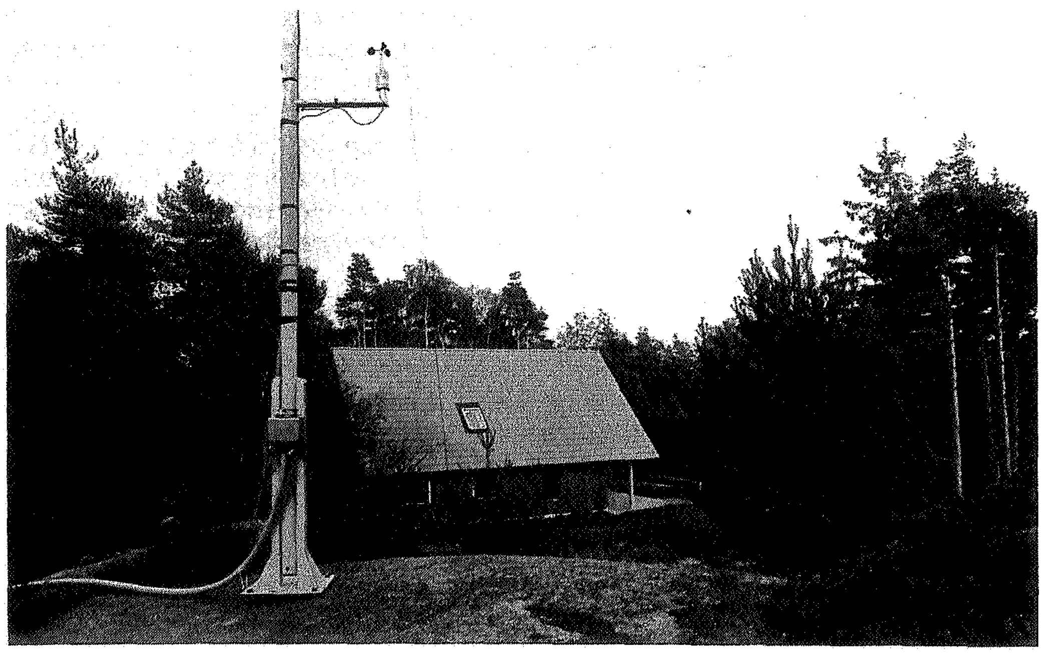


Figure 4. Weather mast and house as seen from WNW. The cup anemometer seen is at the same height as the house ridge.

4.3 Wind pressure distribution monitoring

Pressure taps are distributed around the house perimeter in such a way as to provide useful information about wind pressure distribution.There are also pressure taps in the wall and roof cavities, see figure 5. The cavities will moderate the wind pressures as a driving force for air infiltration. The investigation of this moderating effect is seen as a major feature of the project.

There is a total of more than 250 pressure taps connected to a solenoid valve scanner via plastic tubes with 5 mm inner diameter. All plastic tubes are 25 meters long (altogether ≈ 7000m !) and are hidden in the wall and roof cavities.

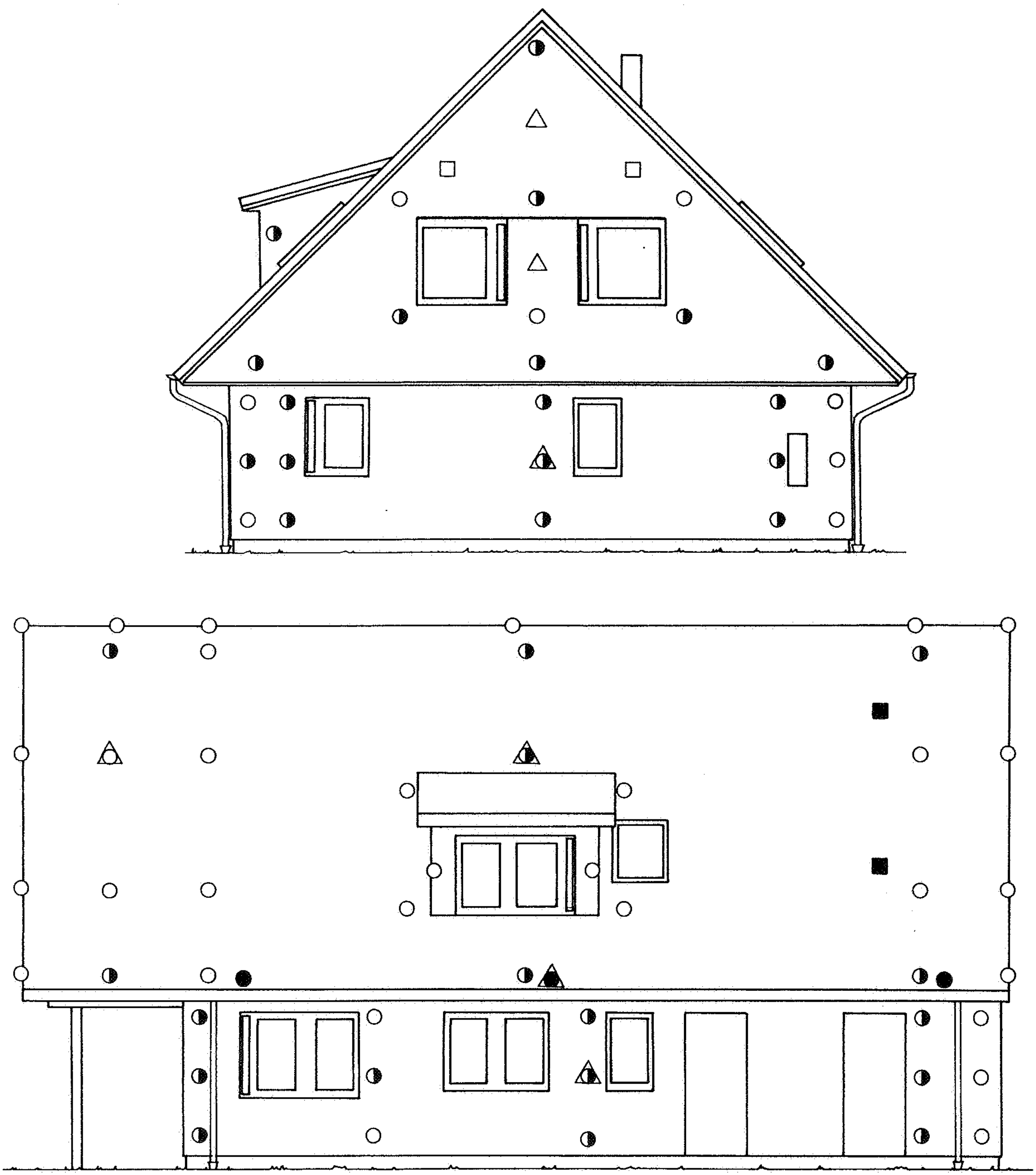
It is important to estimate the stack effect in all the tubes, since serious errors would otherwise occur due to the warming up of cavities by solar radiation on surfaces. The temperatures in the cavities, see figure 5, are measured by thermocouples placed in plastic tubes, both for protection and to get the same thermal inertia as in the pressure monitoring plastic tubes.

The solenoid valve scanner is interfaced to the computer via the analogue scanner and a special relay interface. The valve scanner connects the plastic tubes one at a time to a common, fast, differential manometer shown in figure 6. The reference pressure is that taken at the hall staircase. The time constant to get a 98% reading of the true value is ≈ 250 ms, which gives a useful sampling rate of 2 - 3 readings /s.

The large number of pressure taps means that the only economically possible alternative to a scanner would be a multitube, liquid manometer. The advantages of that instrument are its relatively low cost and that pressure readings from pictures taken can be correlated. The disadvantages are that it is difficult to interface to a real time computer system, it has low resolution and is generaly messy. For this project the disadvantages of the multitube, liquid manometer out-weighed its advantages.

4.4 Flows in ventilation systems

In the mechanical ventilation systems, duct flows are measured by orifice plates (Svenska Fläkt, EHBA). Flow measurements are much more complicated in natural ventilation systems. The flow is often highly irregular and an orificeplate would give low resolution and alter the properties of the system to an unacceptable extent. In this project we shall try to use pulsed ultrasonic transducers, a system which has been developed in collaboration with the School of Electrical Engineering as an M.Sc. project.



○ pressure tap on perimeter
● pressure tap in wall or roof cavity
◑ pressure taps on perimeter + in cavity
■ pressure tap in Rockwool insulation
△ temperature sensor in wall or roof cavity

Figure 5. Pressure taps and temperature measuring sensors on north gable wall and east wall and roof.

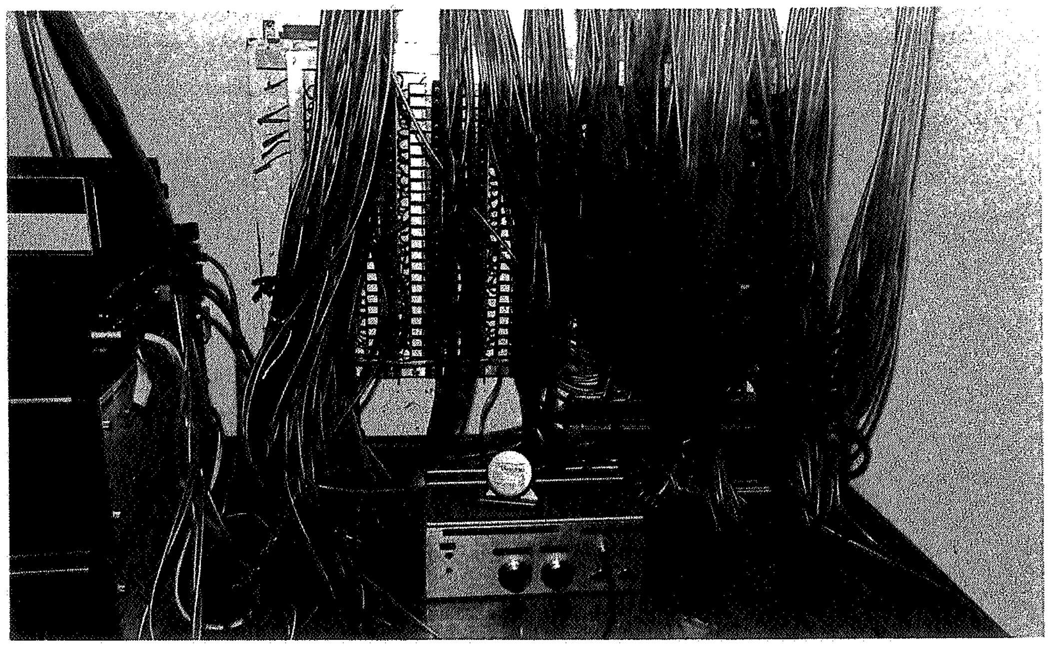


Figure 6. Solenoid valve scanner and Setra differential pressure transducer, with plastic tubes beeing connected.

4.5 Tracer gas measurements

Primarily the decay method has been adopted. The tracer gas analyser is a Miran 101, working with N_2O in the 100 ppm range. Mixing is accomplished by 3-speed table fans, with a free blowing capacity of 60 m^3/minute. The house has already been provided with piping for a constant concentration measuring system. If funds are available, such a system will be adopted giving better accuracy and speed and making it possible to use multi-cell analysis.

5. ACKNOWLEDGEMENTS

The financial support by the National Swedish Building Research Council for this work is gratefully acknowledged.

ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER D

THE IMPACT OF VENTILATION AND AIRTIGHTNESS ON ENERGY CONSUMPTION

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Introduction

The impact of good airtightness and good thermal insulation on energy consumption and indoor climate in a number of detached houses has been described in a CIB report (Elmroth-Lögdberg 1980). All the houses had less than 1,0 air change per hour at 50 Pa - measured through pressure-testing - right after construction.

For the sake comparison, some houses with around 3,0 air changes per hour right after construction were studied. Each house had a floor area of 135 m^2.

Energy consumption

The total energy consumption in the five detached houses was measured over a three-year period. Corrections were made for variations in the number of degree-hours in the area.

The energy consumption of the houses under different periods is shown in table 1:

Table 1: Estimated and measured energy consumption 1978-81

Measurement period	Mean indoor temperature °C	Estimated energy consumption (kwh/year)	Measured energy consumption (mean value for five houses) (kwh/year)
Feb 78-Feb 79	19-20	18 400 - 19 600	18 550
Feb 79-Feb 80	19-20	18 600 - 19 600	18 800
Feb 80-Feb 81	20-21	19 600 - 20 500	19 400

From the table it can be seen that the measured energy consumption corresponds well to the estimate.

The air change was measured a number of times per year, and varied between 0,4 and 0,5 air changes per hour.

Necessary ventilation

From a hygienic point of view, an air change of 4 m^3/person and hour at an indoor temperature of 18^o C and a relative humidity of 60 percent is the minimum requirement to enable the indoor air to contain less than 0,5 per cent CO_2 (the highest value permitted in a work place according to the regulations of the Swedish Board of Occupational Safety and Health). There exists no corresponding figure for dwellings. With regard to such comfort requirements as smell, sufficiently low relative humidity and evaporation from building materials, an air change of 10 m^3 per person and hour is more adequate. (Ubisch, 1977). This means that a master bedroom requires a ventilation of around (10+10+5)=25 m^3/h if two adults and a child are to sleep in it.

Air change in individual rooms

Tracer gas measurements were carried out with the aim of verifying the air change in individual rooms where people spend long time (e.g. bedrooms).

In houses, ventilated through an exhaust air ventilation system, there are as a rule no air outlets in bedrooms, work-rooms etc. Instead, these are located in the wet rooms of the house (bathroom, laundry, W.C.) and in the kitchen. Bad air is blown out through the air outlet. Outdoor air is drawn into the house through air inlets (slot valves), usually placed just above the windows in those rooms where there are no air outlets.

The air change in the bedrooms has been measured in the five houses (which all have an airtightness of less than 1,0 air changes per hour at 50 Pa) and in a number of reference objects which all comply with the requirements of the Swedish Building Code, i.e. 3 air changes per hour at 50 Pa. The air change has been adjusted to the requirements of the Swedish Building Code, (i.e. 0,35 liters/second and m^2). This value corresponds to some 0,5 air changes per hour for the building as a whole.

The results presented here refer to a master bedroom with a floor area of 13 m^2. The doors of the bedrooms closed.

Table 2: Air change with the fan adjusted to 0,5 air changes per hour in the master bedroom with the slot valve open or closed. The bedroom doors were closed.

Fan adjustment	House with tightness of 1,0 at 50 Pa	House with tightness of 3,0 at 50 Pa	Recommended value
0,5 air changes/h valve closed	21	8	25
0,5 air changes/h valve open	29	18	25

According to the table, an air change corresponding to the recommended value of 25 m^3/h is only obtained in very tight houses. The figure also indicate that the slot valves have a decisive impact on the air change of the room.

Measurement of air change when the air flow is disturbed

All the measurements of air change presented above were made in the absence of any disturbances to the air flow, due to e.g. open doors or windows.

It is, however, not unusual that - especially in summer - one or more windows are slightly open for longer or shorter periods of time to air the room.

In order to determine whether the air flow from the master bedrooms was disturbed, measurements were carried out when two windows were slightly open in the living-room. As the windows could be locked in an airing position, with a window chink of only around two cm, this position was chosen for the measurements. The horisontal outer measurement of the window frames was 600 mm. All the measurements were carried out with the slot valves open or closed, and with the fan adjusted to give an air change of 0,5 air changes/h (0,35 liter/sec,m^2). The results of the measurements are shown in table 3:

Table 3: Air change in master bedroom with two windows on the second floor slightly open or closed.

Fan adjustment	Open windows, m^3/h	Closed windows, m^3/h
0,5 air ch/h, valves closed	6	9
0,5 air ch/h, valves open	13	19

The table indicates that the ventilation system is partly short-circuited if two windows are slightly opened (2 cm chink). The average air change was reduced by 45%.

A pilot study with a modified exhaust air ventilation system

On the basis of the experience of the measurements presented above, attempts were made to modify a conventional ventilation system in such a way that a sufficient air change could easily be obtained in e.g. bedrooms while the total air change in the house as a whole was reduced (so called "demand adjusted ventilation").

Experiments have been carried out in an area of 1½-storey row houses without cellars. (Figure 1). In one of the houses, the "measurement house" three additional air outlets were installed in each bedroom (Figure 2). In all other respects, the ventilation system was a conventional exhaust air system. The additional cost of the modification to the system was 500 SEK, including the additional valves and air channels.

Measurements were carried out in the measurement house as well as in an adjacent referense house of the same type. Both houses were constructed with good air tightness (around 1,6 air changes per hour at 50 Pa). The reference house has a conventional exhaust air system with air outlets in all the wet rooms, in the clothes closet and in the kitchen.

In both houses there are air inlets - slot valves - in the windows of all the bedrooms, in the living room and in the hall.

The aim of the construction of the modified ventilation system was to enable a reduction of the total air change (including unintentional ventilation) to some 0,3 air changes per hour with maintained comfort. 0,3 air changes per hour corresponds to a total air change of 80 m^3/h, which is more than sufficient for the four persons living in the house, if the distribution of air flows is good.

The air outlets were adjusted to enable good ventilation in all the rooms - especially in those rooms where persons dwell for longer periods.

For the master bedroom this requires an air change of 25 m^3/h. The air change in the wet rooms was reduced slightly, in comparison to relevant standards.

In the reference house, the fan and the slot valve were pre-adjusted in the factory. The total air change - including unintentional ventilation - was around 0,6 air changes/hour (tracer gas measurement).

Table 4: Measured air change in master bedroom in the measurement house and in the reference house with fan at lowest speed and with the slot valve open or closed as much as possible (half closed). The bedroom door was closed.

Measurement conditions	Measurement house	Reference house
Measured air change in the entire house (air changes per hour)	0,3	0,6
Measured air change in master bedroom (slot valve fully opened) (m^3/h)	24	21
Measured air change in master bedroom with slot valve closed as much as possible (m^3/h)	20	14

The measurements indicate that, in spite of a very low total air change in the measurement house (0,3 air ch/h), the air change in the bedrooms is higher than in the reference house. Thus a great average air change in the house as a whole does not necessarily imply that all parts of the house get good ventilation.

Measurements of air humidity etc. have been carried out since October 1980, and are planned to continue for another year. The results and observations so far indicate that

- air humidity never exceeds 50% in any of the rooms (except, for very short periods, in wet rooms and kitchens)
- condensation has never appeared on the inside of the windows
- there has always been low pressure in the wet rooms
- on average the fan results in 2-5 Pa lower pressure in all the rooms than in the outdoor air.

Thus, through a "demand adjustment" of the ventilation system in such a way that good ventilation is obtained in those rooms where people spend longer periods, the total air change in the measurement house has been cut by around 50 %. The people living in the house have experienced a good indoor climate and have never had the feeling that the indoor air has been stuffy.

The energy losses due to ventilation have been estimated to around 3300 kWh/year which is to be compared to the losses in the reference house which amount to some 6600 kWh/year. With 0,5 air changes per hour (the stipulated value according to the Building Code) energy losses should have been around 5500 kWh/year.

Energy balance for a row house in Öringe, Tyresö

The calculations are made on the assumption of Stockholm's climate and an indoor temperature of 21°C.

Energy losses		Energy supply	
Transmission	8900 kWh/year	Heating system	7100 kWh/year
Ventilation (0,5 air ch/h)	6700	Domestic hot water production	5000
Domestic electricity	1000	Domestic electricity	3500
		Solar irradiation	3000
Drainage water	3500	Heat from persons etc.	1500
	20100		20100

Sum of billed energy	15600 kWh/year	(21°C)
Sum of billed energy	14200 kWh/year	(20°C)

Demand-adjusted ventilation with 0,3 air changes/hour

Sum of billed energy	12900 kWh/year	(21°C)
Sum of billed energy	11700 kWh/year	(20°C)

Actual energy consumption

for the period Sept 1, 1980 - Sept 1, 1981,	12600 kWh/year
for the period Sept 1, 1981 - Sept 1, 1982,	13000 kWh/year

The mean indoor temperature has been 21°C during the period.

Test of air tightness (at 50 Pa)

May 1980	1,6 air changes per hour
May 1981	1,6 air changes per hour

Low indoor pressure

The air pressure indoors has on average been 4-6 Pa lower than the outdoor air pressure, at an average air change (inclusive of unintentional ventilation) of 0,33 air changes per hour.

Other information

Window area 17,3 m^2.

Exhaust air fan in ventilation chimney. Air outlets in the wet rooms and in all the bedrooms.

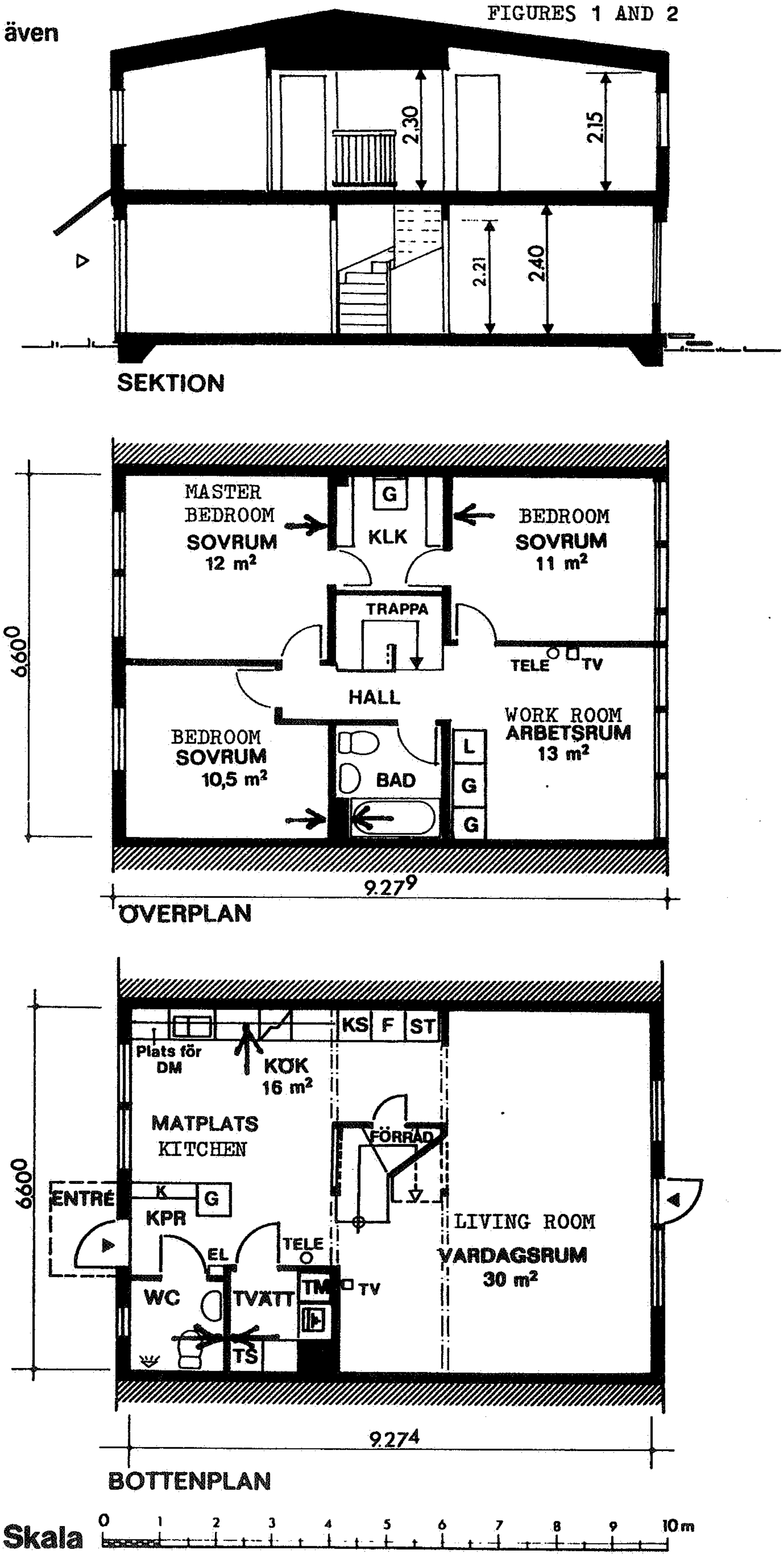
Air change in bedroom (master bedroom) 24 m^3, of which 5 m^3 through over-flow from adjacent rooms.

All measurements of air changes have been made through tracer gas measurement, thus also including unintentional ventilation.

HUSTYP 6 A

Förekommer även spegelvänd.

FIGURES 1 AND 2



ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER E

REDUCTION OF AIR INFILTRATION AND THE DEVELOPMENT OF CONTROLLED MECHANICAL VENTILATION IN FRANCE

(Amended reprint. First published in the 3rd AIC Conference Proceedings, September 1982)

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SYNOPSIS

Since 1974 the french Authorities have insisted on energy being saved in all buildings. There was very strong pressure on manufacturers to obtain better sealed window frames.
In practise less than two or three meters cubed per hour at a pressure of ten pascals penetrates.

Also television campaigns have insisted on weather stripping all windows and window frames in all old buildings.

The result of these campaigns is that all buildings with no or natural ventilation systems actually have indoor condensation problems.
The use of controlled mechanical ventilation systems is well established in France and is present in 80 per cent of multi storey flats and 40 per cent of single family housing.

A new regulation is in preparation and will probably require the fitting of mechanical ventilation in all new buildings.
In the meantime we are to have a new regulation concerning the heat losses in house and flats. This means greater interest in planning of buildings and houses with centralised controlled mechanical ventilation systems with heat exchangers.

Because of this above new regulation we are sure of great developments of our systems in the coming years.

1. VENTILATION OF DWELLINGS : CURRENT STATE-OF-THE-ART AND FUTURE PROSPECTS

Bioclimatic architecture, intensive insulation , improvement of the existing dwelling facilities, ventilation, new heating methods and equipment, regulation and programming are all part of the energy saving inventory. Among these approaches to the problem, ventilation must be highlighted as it is one of the methods most difficult to control yet is of the utmost importance as regards the health and comfort of the occupants, the preservation of the dwelling and energy saving programs.

Ventilation has been subjected to numerous controversies which, it should be stated, are the outcome of many conferences, but we should no longer be satisfied with the approximate approach.

Considerable efforts have been devoted to the reduction of heat losses in new dwellings since 1974 but these efforts have mainly concentrated on improving the thermal insulation characteristics of the external walls.

The new constraints of future regulations, intended to reduce energy consumption will call for higher and higher investments per equivalent tonne of petroleum saved if the solutions adopted are not to jeopardize "comfort". Until now, the improvement of thermal insulation has not been obtained at the expense of the living conditions in dwellings. On the contrary, these conditions have been improved at the same time (less cold radiation transmitted from the external walls, improved heating regulation, controlled air change with mechanical ventilation...), but do we have the resources to continue in this direction ?

The reduction of provisions contributing to comfort is always a difficult decision to take for, if excessive, the improvised means used by the occupants for maintaining the standard of comfort that they require could be contrary to the economic objectives sought after. Thus ventilation, which has become one of the priorities towards which energy saving in dwellings should be orientated, poses a dilemma.

Is it necessary to maintain the air change rates at their present values and reduce the corresponding heat losses by adopting measures of incitement to make heat recovery systems more widespread with reasonable investment figures ?

Or should it be now recognized that the statutory requirements pertaining to ventilation are too "comfortable", with the resulting temptation of reducing the air change rate which, in theory, would enable both the investment and energy consumption levels to be reduced ?

The choice is not easy, it is essential that an analysis of the requirements concerning the new generation of dwellings be undertaken beforehand, for some criteria taken into consideration to justify the requirements of the Decrees dated the 22nd October 69 relative to ventilation no longer have a priority status.

2. THE NEW PRIORITY VENTILATION OBJECTIVE : "PREVENTION OF CONDENSATION"

Probably the most sensible principle for economically ensuring the ventilation of dwellings consists in allowing fresh air to flow into the most important enclosed areas of a building (bedrooms, living rooms, etc...) and then to use this volume of air to replace that in the rooms and spaces allocated to service installations prior to being exhausted outside the building. This is one of the solutions put forward in the Decrees dated the 22nd October 1969 and it is rather a pity that it is not imposed for all dwellings for, besides the resulting energy saving features of this solution, it also provides for integral ventilation of the dwellings and thus prevents the diffusion of polluting emanations and water vapour from the spaces allocated to service installations to the main living areas. Of course, this principle results in a reciprocal state of dependence between the main rooms and those spaces allocated to services, but technological solutions can be found to meet their respective requirements.

Many studies relative to ventilation requirements in dwellings have already been undertaken, especially by the C.S.T.B. to justify the "Examples de solutions pour faciliter l'application du réglement de construction" (Examples of solutions facilitating the application of building regulations) published in November 1971. However, the sharp rise in the cost of energy has resulted in intensive insulation of buildings and lower interior temperatures and their effect on ventilation objectives must be thoroughly examined.

The rooms and spaces set aside for service facilities are generally the starting point for very strong yet short lasting polluting emanations. The rapid increase in the pollution level in these areas is noticed by the occupants who feel that a higher air change rate is required. These service rooms and spaces temporarily justify an increased ventilation rate which must be noticeable by the occupants of the building (noise, luminous indicating devices..)or be provided with a timing system so as to avoid ommissions and thus restrict its use to only the most effective periods.

Besides the greater temperature rises in the well insulated kitchens with a low thermal inertia, the development in construction techniques has not changed the ambient conditions in the rooms and spaces set aside for service installations. These areas are designed to temporarily support high pollution rates without suffering from any notable damage, and a reduction in their ventilation facilities could be considered. However, any reduction in a high ventilation operating rate would have a negligeable influence as regards the energy consumption as its normally limited operating time (less than 10 %) would have to be increased to compensate for a loss of instantaneous efficiency.

In the main rooms of a building, the quality of the air degrades insiduously and is polluted by the direct emanations of the occupants at a slow but constant rate. The increase in the pollution level is hardly perceived for, being progressive, it leads to the human organism becoming accustomed to the environment and does not call for any change in the ventilation of the rooms. The ventilation installation must therefore provide for an idling air change rate with allowance made for the potential requirements of the main rooms, even if they are unoccupied, or be capable of automatically adapting its operating rate to the changes in the ambient conditions.

In the main rooms, the emission from the occupants mainly consists of carbon dioxide, water vapour and organic substances which encourage microbial activity, and the concentration of carbon dioxide is often selected as an indication of the coefficient of pollution to justify the ventilation objectives. The selection of such a coefficient is certainly sufficient for well heated and well ventilated rooms but the concentration of CO2 which is hardly affected by the structural characteristics of the external walls of buildings and by the interior temperature cannot give an indication of the humidity level in the ambient air and therefore, does not permit evaluation of the risks of condensation resulting from a reduction in the number of air changes and the temperature in the new generation of dwellings.

It is an accepted fact that the humidity level in the main rooms of dwellings depends on the occupation and the air change rate, but, it also depends on the interior temperatures. In older types of dwellings, when the humidity reaches a high level, it also depends on the condensation formed on single-glazed windows and the moisture diffusion through the walls, although quite slow, often results in other more vulnerable sections of the building not being exposed to condensation. In the new buildings, these protective features are not present, owing to the use of vapour barriers to protect the insulating materials, together with the inclusion of double-glazed window units and efficient shutters and, therefore, it is the responsibility of the ventilation installation alone to oppose the damage caused by humidity.

Prior to recommending that the idling rate of air changes be reduced, its effects on the conditions of hygiene and the risk of local condensation should be established. This calls for preliminary evaluations as regards the concentration of CO_2 and the relative humidity in the main rooms normally occupied. To clearly show the influence of the different factors which determine the quality of the air, the following text is devoted to bedrooms, which are the areas of a building in which we have encountered the most damage caused by faulty ventilation during our surveys.

2.1 Development of the CO_2 concentration and relative humidity in a bedroom according to the fresh air flow rate.

- Emission of 15 liters/hour of CO_2 and 40 g/h of water vapour per person allowing for the reduced metabolism when sleeping ;
- 90 % exterior relative humidity during the heating season and the night ;
- Bedroom with a volume V (m3) occupied by two persons, doors and windows closed and provided with an air change flow rate of Q (m3/h).

The curves in Figure 1 show the development in the concentration of carbon dioxide (CO_2) according to the occupation time. These curves are established by means of the calculations given in Appendix 1. They show that, for the same ventilation flow rate, the concentration of carbon dioxide is practically independent of the volume of the bedroom when the occupation period is more than several hours and that the increase in concentration is slower as the volume of the room is increased. Thus, nothing justifies the requirements that air changes should be proportional to the volume of the bedrooms. On the contrary, the slight inertia of small bedrooms could justify higher flow rates.

Curves 1 and 2 in Figure 2 represent the development of the relative humidity in a 25 m3 bedroom for an air change flow rate of 15 m3/h, and for very different interior temperatures T_i and exterior temperatures T_e. Under these same conditions, curve 3 represents the carbon dioxide content independent of the temperatures. The curves of this figure show the relative humidity is very dependent on the exterior temperature and the heating and that its development cannot be estimated from the development of the carbon dioxide concentration values. The calculations pertaining to these curves are given in Appendix 2.

The curves in Figure 3 show the percentage of days with heating, and during which a specified humidity level is reached or exceeded in a bedroom occupied by two persons. The heating season considered is limited to all days when the exterior temperature is no higher than 13° C so as to allow for free heat inputs in well insulated dwellings. The different curves correspond to well defined heating (T_i) and ventilation (Q) conditions and to the frequencies of the exterior temperature T_e in area B.

Thus, in the case of a bedroom occupied by two persons and heated to a temperature of 16° C during the night, if the ventilation flow rate is 15 m3/h, the number of days when the relative humidity can exceed 85 % represents 60 % of the days included in the heating period. If these high moisture contents are attained too often, they would sustain conditions of hygiene having harmful consequences on the occupants. If the ventilation flow rate is 30 m3/h (value corresponding approximately to the current regulations in force), it can be seen that the days when the inside humidity level can exceed 85 % represent only 18 % of the total when the interior temperature is 16° C and, if this temperature is 19° C, this inside humidity level is never reached.

Besides the unhealthy living conditions for the occupants, an excessive relative humidity gives rise to the formation of condensation which has untold damaging effects as regards the construction.

2.2 Risks of condensation in main rooms

To thoroughly understand the conditions in which condensation is formed, it must be remembered that :

- the weight of water vapour that can be contained in the ambient air is limited. When this limit is reached, saturation occurs : the relative humidity is at 100 %. This limit depends on the air temperature ; the higher the temperature, the higher the limit. Thus, for a given water vapour density, the air cannot be cooled below the dew point temperature without the resulting formation of condensation ;
- if the distribution of the water vapour in the room is homogeneous, the same principle does not apply for the temperature and, if it is locally lower then the dew point temperature, condensation starts to occur.

The ambient temperature Ti in a room is a fictictious temperature which, when evenly distributed, causes the same heat exchanges with the occupants as the actual heterogeneous temperatures in the effective occupation area. The surface temperature θ, of an external wall is lower than T_i ; it depends on the degree of thermal insulation that it provides and the heat exchanges of its interior lining with the other walls by radiation and with the air through the convection process. The calculation of θ_i is of the utmost importance as it enables precautions to be taken against the formation of condensation.

The surface temperature (Fig. 4) θ_i on the typical section of a flat external wall can be calculated by using formula (1)

$$\theta_i = T_i - \frac{K}{h_i} (T_i - T_e) \quad (1)$$

where

- T_e exterior temperature
- K coefficient of thermal transmittance in W/m2° C
- h_i coefficient of interior surface heat exchange in W/m2° C of which the conventional values adopted in the D.T.U. (Rules Th-K77) are :

- h_i = 9 W/m2° C for vertical walls
- h_i = 11 W/m2°C for ceilings or roofs
- h_i = 6 W/m2°C for floors.

For typical sections of double-glazed windows (K = 3 watts/m2° C) :

$$\theta_i = T_i - \frac{T_i - T_e}{3}$$

condensation will be formed if the relative humidity is high ; but these surfaces can tolerate condensation without being damaged.

For a well insulated wall (K = 0.55 W/m2°C)
$\theta_i = T_i - 0.06\ (T_i - T_e)$, the surface temperature is very close to that of the ambient temperature and the risks of condensation are excluded. The same does not apply for certain special points where the formula (1) with conventional h_i values cannot be applied and the most vulnerable are formed by :

a) The junctions of several load-bearing walls with a floor (Fig.4)

- The thermal insulation in this area is reduced and the transmittance of heat outside the building is increased.

- The convection air flows avoid these corners which offer to much resistance to the air, and the radiation heat exchanges of these low points are often hindered by the furniture. The local h_i coefficient can often attain a value of 4.5 watts/m2°C.

- The convection air flows which hug the external wall are responsible for maintening a lower temperature at the floor level than that at the medium height of a room.

On the ground floor of a well insulated detached house, the difference can be as much as 1° C.

b) The junctions of the window sill and walls or the thresholds of French windows with the floors when there are curtains (Fig. 5).

The space behind the curtains forms a duct filled with a down flow of convected air which is considerably cooled upon contact with the glazed surfaces. This flow of air maintains a very low surface temperature at the junction. To this factor can be added the masking effect of the curtains which reduces the heat exchanges with the interior walls by the effect of radiation.

Condensation can then start to form on the glazing and also at the junction.

c) The junctions of the floors with the side walls against which are arranged ward-robes or cupboards (Fig. 6).

In this case, the volume filled with clothes forms a barrier, the thermal resistance of which can have the same magnitude as that of the wall and the air flow which circulates very slowly between the wall and the cupboard cools down and reaches a temperature low enough at the junction for the formation of condensation when the ambient humidity is high. From these few examples detailed above, it can be shown that in recently constructed dwellings, and because of the building techniques or the normal interior appointments installed by the occupants, the surface temperature of the walls θ_i can in places often attain :

$$\theta_i = T_i - \frac{T_i - T_e}{3} \quad (2)$$

and that the ventilation has to maintain a relative humidity such that θ_i is greater than the dew point temperature so as to avoid the formation of condensation.

Thus, in case (a), if the thermal resistance at the junction corresponds to a coefficient of $K = 1.35\ W/m2°C$ and if $h_i = 4.5\ W/m2°C$, we obtain $\theta_i = T_i - 1.35/4.5(T_i - T_e)$

$$= T_i - \frac{T_i - T_e}{3}$$

It should be noted that during the night, the temperature (2) can often be lower that that of a double-glazed window unit provided with good quality solid shutters corresponding to $K = 2$ and $h_i = 9$.

Therefore at $\theta_i = T_i - 0.22\ (T_i - T_e)$ and that the condensation can appear locally on the walls before being deposited on the glazed surfaces.

The curves given in Figure 7 correspond to a bedroom occupied by two persons during the night. This curve shows the minimum air change flow rates needed to prevent the formation of condensation and mildew at the vulnerable points characterized by a surface temperature of :

$$\theta_i = \frac{T_i - T_e}{3}$$

(the determination method is given in Appendix 3). These flow rates are given according to the interior and exterior temperatures (T_i and T_e, respectively). Figure 7 also shows the percentage of hours in the heating season ($T_e < 13°$ C) during which the exterior temperature is higher than the value T_e.

Examples : If Q = 15 m3/h and T_i = 16° C ; as soon as the average exterior temperature is higher than 2° C, the interior humidity level is excessive and local condensation can be formed. 75 % of the days during which the heating is operating are thus concerned by these conditions which are favourable to the formation of condensation :

- If Q = 15 m3/h and T_i = 19° C, 32 % of the days are concerned,
- If Q = 20 m3/h and T_i = 16° C, 34 % of the days are concerned, but if T_i = 19° C, the risks are averted.

The curves in Figure 7 show that, contrary to certain currently accepted ideas, the most favourable conditions for the formation of condensation and mildew correspond to the hottest periods of the heating season which are situated at the half-way point. They also show that the lowering of the ambient temperatures to reduce the energy consumption due to heating installations considerably increases the risks when the level of ventilation is low.

Public health specialists readily acknowledge the fact that carbon dioxide concentrations of less than 3 liters/m3 cause no health hazards and that the ventilation of a bedroom could be permanently reduced to a rate of a 10 m3/h without causing harmful effects, but the previous analyses indicate that such a reduction is impossible without the humidity having damaging effects on the occupants and the construction. The ventilation flow rates in the main rooms must be determined so as to prevent any condensation.

The factors contributing to the development of condensation in the main rooms are multifold (occupation, interior and exterior temperatures...) and extremely variable. Furthermore, the conditions favourable to the formation of condensation are not perceptible by the occupants and consequently, the adaptation of the air changes to the requirements of the main rooms cannot be left to the initiative of the occupants.

Ventilation installations must therefore be designed to provide for the following requirements in the main rooms :

- either a permanent minimum air change which prevents the risk of condensation under normal occupation conditions (two persons per bedroom, for instance), for lower interior temperatures selected by the occupants so as to reduce the heating costs (16° C in the bedrooms, for instance) regardless of the exterior temperature, or

- an air change automatically adapting to the requirements. Such solutions to the problem have not yet been incorporated in dwellings but the technological progress in the fields of detection servocontrol systems should allow for their future development.

These installations must also conciliate these objectives with the current priority "energy saving".

APPENDIX 1

Development of the carbon dioxide concentration in a bedroom occupied by two persons :

$$C = C_e + \frac{q}{Q}\left[1 - e^{-\frac{Q}{V}t}\right]$$

C (l/m3)	: concentration in the bedroom
C_e(l/m3)	: concentration of CO2 in the inlet air 0.3 l/m3
q(l/h)	: CO2 emission by the occupants
Q(m3/h)	: ventilation flow rate
V(m3)	: bedroom volume
t	: time in hours
Assumption	: q = 30 l/h for two sleeping occupants.

APPENDIX 2

Development of the relative humidity in a bedroom occupied by two persons.

If the condensation is negligeable and if the water vapour cannot be discharged by diffusion, the increase in the absolute humidity rate follows the same law as that specific to carbon dioxide but with C_e variable according to the exterior temperature.

Assumptions :

- $q = 80$ g/h for two sleeping occupants
- 90 % exterior relative humidity at night
- C and C_e are expressed in g/m3.

The relative interior humidity can be calculated from the known absolute humidity C and the interior temperature T_i.

APPENDIX 3

The absolute humidity in a bedroom occupied by two persons reaches the following level after several hours :

$$C(g/m3) = C_e(g/m3) + \frac{q}{Q} = C_e + \frac{80}{Q}$$

with C_e, the absolute exterior humidity corresponds to T_e and 90 % R.H.

A dew point temperature T_r corresponds to each value of C and if the surface temperature

$$\theta_i = T_i - \frac{T_i - T_e}{3}$$

is less than T_r, condensation is formed.

Each temperature couple (T_i, T_e) has therefore a corresponding ventilation flow rate Q, below which there is a risk of condensation.

The curves in Figure 7 show the limits of Q as a function of T_i and T_e below which condensation can start to form.

Example : if T_i = 16 and T_e 2°C, condensation can be formed if Q less than 15 m3/h.

3. VENTILATION AND ENERGY SAVINGS IN DWELLINGS : "BEWARE OF MIRAGES"

The new draft regulations concerning the ventilation of dwellings were presented at the Cated-C.S.T.B. one day technical meeting held the 11th June 1981. The orientation chosen to limit the heat losses is clear; but it only incites the interested parties to reduce the air changes and thus dissuades them from recovering the energy sources contained in the air.

In fact, it authorizes the provision of minimum services which will be adopted straight away as the sole objective for reducing the conventional evaluation of coefficient G to the least cost, but will the technological resources used and the behaviour of the occupants as regards these new ventilation conditions allow for gains in heating values of an importance that cannot be anticipated by the theoretical calculation of G ?

We will attempt to answer this question by presenting the heat losses due to ventilation and the theoretical energy gain resulting from a reduction in the air change rate when conventional assumptions concerning the way of life of the occupants and the influence of spurious factors are accepted. We will then attempt to assess the actual gains corresponding to concrete representative examples of current situations.

Finally, the economic aspect of ventilation cannot be dealt with, without tackling the problems specific to the extraction of burnt gases, when boilers or water heaters are installed throughout dwellings, and without drawing attention to the interest as regards the recovery of heat from the foul air or the burnt gases.

4. INFLUENCE OF VENTILATION ON THE CONSUMPTION OF ENERGY IN HEATING INSTALLATIONS

4.1 Heat losses due to air changes and heat gains due to reduction of the air change rate

For an actual air change flow rate Q in m3/h, the instantaneous heat losses are given by the following formula :

$$d_v(\text{watts-hours}) = 0.34 \times Q_r \times (T_i - T_e),$$

with T_i, being the estimated temperature of the extracted air and taken as the average temperature in the dwelling, and T_e being the exterior temperature.

The overall heat losses D_v during a heating season are equal to :

$$D_v(\text{watts-hours}) = 0.34 \times Q \times DH\ (t_r)$$

where DH (t_r) represents the number of degrees-hours for a reference interior temperature t_r. DH (T_r) is shown in Table 1 taken from D.T.U. (Rules Th-G77) of November 1977.

Example : 80 m2 (200 m3) flat with an approximate average air change rate of one volume per hour in the main rooms, in compliance with the current regulations in force,

Q average = 140 m3/h if $T_i = t_r$ = 18° C

- in area A :
  DH(18) = 73 088 and $D_v \simeq$ 3 500 kWh ;
- in area B :
  DH(18) = 62 928 and $D_v \simeq$ 2 999 kWh ;
- in area C :
  DH(18) = 43 774 and $D_v \simeq$ 2 100 kWh.

If the average actual flow rate can be reduced by 30 % (magnitude complying with the objectives of future regulations) without causing disturbances in construction or discomfort for the occupants, the heat losses in areas A, B and C can be reduced by 1 050 kWh, 900 kWh and 630 kWh, respectively.

4.2 Influence of occupant behaviour

The strict application of impending regulations will imply overall ventilation flow rates that can almost be doubled at the initiative of the users. The occupants will in fact have the choice between a normal rate, which in most cases will correspond to the minimum overall flow rate required, i.e. : Q(min) = 15(n + 2),

with n being the number of main rooms in the dwelling concerned and an accelerated ventilation rate for meeting intensive, but temporary, requirements in kitchens and possibly in bathrooms, with extraction rates higher than the statutory values depending on the number of main rooms. Thus, in a four-room dwelling, the accelerated ventilation rate in the kitchen should allow for an extraction of at least 120 m3/h from this area. Attention must be drawn to the authorization as regards the ventilation of bathrooms at a fixed flow rate of 15 m3/h.

The anticipated heating gain from these new arrangements obviously depends on the conventional assumptions concerning the utilization time of the different ventilation flow rates, but, the actual gains could be much lower if the accelerated ventilation rate is used more often than expected. This is not a new problem ; the examples of the C.S.T.B. solution for facilitating the application of the Decrees dated 22nd October 1969 concerning the ventilation of dwellings, already recommend air extraction vents that can be adjusted by the occupants, particularly in the kitchen, but the variations relative to the resulting air change are not as great as those considered in the future and the uncertitude as regards the actual heat losses due to ventilation will be amplified by the new arrangements. The excessive use of the accelerated extraction rate can have several reasons :

. Forgetfulness : as we have already pointed out, the intensive emissitions in the kitchen are quickly noticed and incite the occupants to increase the ventilation rate, but the return to proper ambient conditions when the very polluting activities have ceased cause no inconvenience and, in general, nothing warns the occupants that the ventilation system is still operating at the accelerated rate. During site visits, it can often be seen that the extraction vents in kitchens are always in the maximum position and many ventilation installers prematurely conclude that adjustable flow rate vents serve no purpose ;

. The controls for the ventilation vents are often difficult to operate or inaccessible and the occupants resign themselves to permanently maintaining a maximum flow rate ;

. The lack of information. Members of the ventilation Trade are aware of the heat losses due to air changes but, in general, they do not provide the occupants with this information and the means at their disposal are often badly exploited ;

. An insufficient or badly distributed normal ventilation rate which is not effective against the formation of condensation and mildew. The minimum overall flow rates authorized by the draft regulation for the normal ventilation rate are sufficient for solving the problems in the main rooms, provided that the fresh air introduced is correctly distributed between all the rooms according to their respective occupation coefficient ; but, if the current design concepts, which are based on the uniform and constant distribution of inlet air between all the bedrooms (with twice the flow rate in the living rooms), are retained, the air change flow rates in the bedrooms will attain a maximum value of 18 m3/h if there is no spurious air admission into the other rooms. In bedrooms occupied by two persons and in which the temperature is lowered (16° C during the night, for instance), these flow rates are too low. As shown by the curves of Figure 7 in the first part of this article, the conditions favourable to the development of mildew will be encountered too often. Faced with these situations, the occupants will adopt solutions to the problem which are not economical from the energy saving point of view ;

. Maintained accelerated ventilation rate which unnecessarily increases the overall ventilation values for a dwelling, or the opening of windows ;

. Higher interior temperatures : 18 to 19° C. In fact, it should be recalled that two means can be used for the prevention of condensation ; heating and ventilation, but, the latter approach to the problem is more economic. This fact is clearly illustrated by the example given below.

Example : A bedroom designed for two persons which can be subjected to two distinct ventilation and heating conditions corresponding to equivalent risks of condensation :

a) First configuration :

Volume : 30 m3 $\quad$ G = 1 watt/m3°C,

Q = 18 m3/h $\quad$ T_i = 19° C

Heat losses in area B,

$$D = 1 \times 30 \times \frac{DH(19)}{1\ 000} = 2\ 058 \text{ kWh}$$

b) Second configuration :

Q = 27 m3/h, $\quad$ T_i = 16° C

$$D = 1 \times 30 \times \frac{DH(16)}{1\ 000} + 0{,}34 \times (27 - 18) \times \frac{DH(16)}{1\ 000} = 1\ 713 \text{ kWh.}$$

If, in the first configuration T_i = 19° C for half of the time and T_i = 16° C during the other half, the heating energy consumption is still greater than that of the second configuration (1 806 kWh).

We thus draw the attention of the interested parties to the minimum requirements concerning the bathrooms, i.e. a fixed flow rate of 15 m3/h. This tolerance should not be abused, for in many cases it does not allow for the suitable extraction of humidity resulting from the taking of a bath or shower and also from the drying of linen. The drying rate depends on the air change rate and the relative humidity of this air, and therefore, its temperature. Consequently, to solve their problems, the occupants will attempt to modify the original setting of the extraction vents when this operation is easy, or will constantly keep the heating at a temperature higher than 20° C.

4.3 Influences of technological resources used for ventilation

From the project of the future regulations, it can be thought that it is possible to considerably reduce the heat losses due to the air changes without any precautions and without investments higher than those previously encountered. This is not the case as the more the flow rates are adjusted to suit the requirements, the more it will be necessary to install efficient equipment for properly controlling the air.

The most current solutions presently adopted consist in extracting the foul air from the rooms and areas devoted to service installations by means of mechanical extraction equipment or natural draught and allowing the fresh air to flow in through air inlets which are, in general, self-adjustable and located on the facades of buildings.

If these solutions are retained, the air inlets must allow for sufficient openings to allow the air to penetrate without offering too much resistance when under accelerated ventilation conditions.

When the amplitude of the adjustment left to the initiative of the occupants is too great, the passage of the air inlets is excessive for the normal ventilation rate and the wind generates a supplementary cross ventilation which considerably attenuates the interest of major reductions in the extraction rates. For this purpose, mention should be made of the rules Th-G77 of the D.T.U. dated November 1977 relating to the calculation of the air change flow rate to be taken into consideration for heat losses from buildings ; they allow for the extraction and also for the air intake devices. These rules specify that the ventilation specific flow rate q_v to be considered is equal to the greater of the two following values :

- Σq_e sum of the typical flow rates of self-adjustable air inlets,
- Σq_s sum of the flow rates for which the specific air outlet devices are designed. In the case of an adjustable flow rate in kitchens, the calculation of q_s is made by adopting the minimum flow rate increased by 15 m3/h.

If these conventional rules are maintained, the air inlets, designed for the admission of the overall maximum flow rate corresponding to the accelerated ventilation rate, will always have a leading role and the interest of high reductions in the extraction flow rates under normal ventilation conditions will never be in evidence. These rules excessively penalize the options combining self-adjustable inlets and mechanical extraction with flow rates that can be adjusted by the occupants, but one must be aware of the fact that beyond a certain adjustment amplitude, these solutions are no longer suitable as can be seen from the example given below.

Example : Estimation (See "Calculation methods and assumptions" in the article written by P. Jardinier : "Ventilation et transparence à l'air des habitations", "Cahier techniques du Moniteur", n) 27, Feb-March 1980) of the influence of wind in a dwelling with double exposure (Fig. 8)by adopting the ideal assumption of negligeable spurious leaks. From Figures 9 a, 9 b and 9 c, it can be seen that :

- when the wind is at a zero level, the extraction flow rate is equal to the admission flow rate and the air intake is homogeneously distributed between the inlets ;

- when the wind load on facade n° 1 increases, the air admission is unbalanced and the extent of this imbalance depends on the extraction equipment and flow rates ;

- beyond a specified wind speed, more air enters from facade n° 1 than is discharged through the extraction vents and grilles. The excess air volume flows out through the air inlets on the opposite facade which results in "cross ventilation".

First configuration : Mechanical extraction.

Mechanical extraction of 30 m3/h from the bathroom and toilet and an adjustable flow rate of 60 to 120 m3/h in the kitchen for a depression of 8 mm water gauge at the vents when the air admission meets a negligeable resistance, i.e. when window is open.

Admission of air through five facade installed inlets each offering a resistance of 10 pascals for 30 m3/h. This first configuration corresponds to typical current installations and to the examples of solutions recommended by the C.S.T.B.

The extraction flow rates are practically independent of the wind. Average flow rates : 57 m3/h in the kitchen, 28 m3/h in the bathroom and toilet for the normal ventilation rate ; 111 m3/h in the kitchen for the accelerated ventilation rate.

The flow rates for the air inlets according to the wind speed are indicated in figure 10. It can be seen that the flow rates of the air inlets on facades 1 and 2 are 23 m3/h under normal ventilation conditions when there is no wind. On facade 2, the flow rate reaches 15 m3/h when the wind speed $V \approx 3$ m/s. It is reduced to zero at a wind speed of 4.8 m/s and above this speed, the air flows out through the air inlets installed on facade 2 which results in cross ventilation and the air change in the dwelling exceeds the theoretical value of 120 m3/h.

2nd configuration : Mechanical extraction

With the objectives of the new regulations. Extraction of 15 m3/h from the toilet, 30 m3/h from the bathroom and 45 m3/h from the kitchen at the normal rate.

As the overall flow rate at the accelerated ventilation rate is high, the air inlets are identical to those of the first configuration. The extraction flow rates are stable. in the kitchen 44 m3/h, 15 m3/h in the toilet and 29 m3/h in the bathroom.

Figure 4 shows that the flow rates at the air inlets all have a value of 18 m3/h under normal ventilation conditions and in the absence of wind. As soon as there is a slight amount of wind, the flow rates at facade 2 become too low and the occupants have to maintain the accelerated ventilation rate or half-open a window to ventilate the corresponding rooms, When $V \simeq 3$ m/s, these air inlets only allow 5 m3/h of air to enter and when V is higher than 3.5 m3/s, the air circulation is reversed and cross ventilation occurs.

For wind speeds higher than 4 to 5 m/s, the admission air flow rates at facade 1 are close to those described for configuration 1. Thus, the air change rates in these two configurations is practically the same in spite of different extraction rates.

3rd configuration : Natural ventilation

Same objectives as the first configuration.
Draught assumptions

- 5 m high vertical evacuation ducts (last levels of blocks of flats or individual houses) projecting outside at a level higher than any close obstacle ;
- Average temperature in the dwelling 20° C ;
- Average exterior temperature 7° C ;
  (With allowance made for the low power of the natural phenomenon which generates an average draught of less than 10 pascals to overcome the resistance of the air inlets, the interior doors and the extraction devices) ;
- The cross section of the air inlets is more than twice that of the air inlets used for mechanical extraction installations. They oppose a pressure loss of 2 pascals for 30 m3/h ;
- The evacuation devices (outlet grilles + ducts + outlet) oppose a pressure loss of 3 pascals for their designed flow rates ;
- Average wind speed of 4 m/s.

  In Figure 11 indicating the flow rates of these air inlets according to the wind speed, it can be seen that :

- without wind, approximately 20 m3/h flows in through each of these air inlets at facades 1 or 2 ;

. as soon as there is a slight amount of wind, the admission is very quickly unbalances ;

. when V (wind speed) = 2.10 m/s, there is no flow rate at facade 2 and all the air enters at facade 1 ;

. when V is higher than 2.10 m/s, cross ventilation occurs and the air change is greater than the objectives (120 m3/h).

Figure 12 shows the development curves of the overall flow rate evacuated and the overall air change flow rate under normal ventilation conditions. Half of the overall evacuated flow rate is from the kitchen, with the remaining half being sub-divided between the toilet and bathroom. The difference between two flow rates is due to the cross ventilation. All these values correspond to well defined influence of the wind blowing against facade 1.

Under average conditions corresponding to a wind speed of 4 m/s homogenously distributed from all directions, and in winter, calculations show that the following are obtained under the normal ventilation rate :

- air change flow rate of 133 m3/h instead of 120 m3/h ;
- extraction rate in kitchen of 56 m3/h instead of 60 m3/h ;
- extraction flow rates from bathroom and toilet of 28 m3/h instead of 30 m3/h.

Under the accelerated ventilation rate, an extraction of 100 m3/h instead of 120 m3/h is obtained in the kitchen and 25 m3/h is obtained in the bathroom and toilet.

4th configuration : Natural ventilation

Same draught assumptions and same air inlets as the third configuration.

Figure 11 shows that :

. without wind, approximately 17 m3/h flows in through each of the air inlets ;

. the admission unbalance is caused sooner than in the third configuration and, when $V \simeq 1.5$ m/s, the flow rate of the air inlets at facade 2 is already zero ;

. when V is higher than 1.5 m/s, cross ventilation occurs.

Figure 12 shows that half of the overall evacuated flow rate is from the kitchen, with a third from the bathroom and a sixth from the toilet. When the wind speed is higher than 2 m/s, and according to the orientation indicated in Figures 9a, 9b and 9c, the volume of air admitted at facade 1 is close to that of the third configuration and the air change rates are very similar in both configurations.

When V = 4 m/s and the wind is homogeneously distributed, in winter, the following average values are obtained :

. air change flow rate of 120 m3/h instead of 90 m3/h

. extraction rate in kitchen of 45 m3/h, 30 m3/h in bathroom and 15 m3/h in the toilet (these are the desired values)

. under the accelerated ventilation rate, 102 m3/h in the kitchen instead of 120 and 13 m3/h and 26 m3/h in the toilet and bathroom, respectively.

It can thus be seen that the air change flow rate deviates even more from the objectives and is only 10 % less than that of the third configuration.

5. HEAT RECOVERY BY MEANS OF STATIC HEAT EXCHANGERS

Heat pump and static heat exchangers are currently available for the recovery of energy from foul air prior to discharge outside the building.

At first sight, the air-to-air dual flow pump appears to be the most attractive ; but, its operating characteristics are badly suited to heating and ventilation requirements in new and very well insulated dwellings ($G \leqslant 1$).

As a general rule, the control cannot be accomplished room by room when the pump, which has priority, can supply all needs. A major part of the free heat sources (internal or solar) is thus wasted because of a centralized control system. In addition, this wastage causes discomfort :

. The modulation of the interior temperature according to the periods of occupation is limited. The operation of the installation is disturbed or impossible when the interior reference temperature, in the event of temporary unoccupation, is lower than 14° C ;

. The occupants cannot obtain, to their liking, different temperatures in each of the rooms and thus reduce the heating in unoccupied rooms ;

. These operating conditions are badly suited to the adjustment of extraction flow rates left to the initiative of the occupants. The ventilation flow rate must often, and permanently, correspond to the accelerated rate to be effective during peak hours and the heat losses caused by air changes are unnecessarily increased.

Heat recovery by means of theoretically less ambitions heat exchangers is rather a "rustic" but sure solution which is well suited to dwellings for the utilization and maintenance constraints are extremely limited and of low cost. This system is independent of the heating installation and thus provides the occupants with complete liberty as regards the control of their heating. It can be assimilated with an insulation improvement.

5.1 Heat recovery from foul air in double-flow ventilation installations

The expected results from certain operations accomplished during the last few years have not always been confirmed in actual fact. In these cases, the analysis of the situation shows that the factors responsible for the deceiving results are :

- Specified performance data not corresponding to reality. Today, there is a test standard E 51-702 and the manufacturers can guarantee the quality of their equipment as a result of tests carried out by CETIAT in compliance with these standards ;

- Incorrect balancing of the flow rates and leaks in the extraction system prior to entering the heat exchanger, resulting in preliminary cooling of the foul air by mixing with the exterior air. These faults are easy to rectify ; but, the attention of the installers must be drawn to their consequences and they will not hesitate to carefully carry out the necessary operations ;

- Heat losses from the air between the interior of the dwelling and the heat exchanger in the extraction or blowing systems. This factor is, in general, preponderant. It is difficult to provide the air ducts with a good insulation. We are in favour of the solutions which are beginning to appear and which consist in arranging inside the heated volume, constituted by the dwelling, the heat exchanger and the interconnecting system of the rooms served by the heat exchanger. Thus, the heat losses are negligeable. Figure 13shows a double-flow collective ventilation system with individual heat recovery which resolves all the problems mentioned above and which also complies with the present preoccupation of individualizing the heating costs.

Calculation of energy recovered from foul air :

For a specified flow rate, a heat exchanger is characterized by its efficiency :

$$= \frac{T_1 - T_2}{T_3 - T_1}$$ (See Figure 14)

This efficiency is practically independent of the temperatures in the normal operating range.

In the case of an installation comprising a heat exchanger in the dwelling, the efficiency of the installation is nearly the same as that of the heat exchanger and the energy recovered E_r from the foul air is :

$$E_r(\text{kWh}) = \frac{0{,}34 \times q \times \varepsilon \times DH(t_i)}{1\ 000}$$

where q is the ventilation flow rate, ε the efficiency of the heat exchanger and $DH(t_i)$ degrees-hours corresponding to an average temperature t_i.

Example : dwelling of 100 m2, 250 m3 with an average value of $q = 165$ m3/h, $t_i = 18°$ C ;

in area B, DH (18) = 62 928 ;

$$E_i = 2\ 471 \text{ kWh}, \quad \text{if } \varepsilon = 70\ \%.$$

To calculate the energy gain G, allowance must be made for the consumption of the blowing fan which can easily not be more than 40 watts per dwelling, or approximately 350 kWh per year :

$$G_a = \frac{E_r}{R} - 350$$

if R is the efficiency of the heating installation.

Thus, in the case of well regulated direct electric heating system, $R \simeq 1$ and $G \simeq 2\ 100$ kWh.

5.2 Heat recovery from foul air and burnt gases

When the gas-fired boilers are installed in the kitchens and the products of combustion are evacuated by mechanical extraction together with the foul air, the interest of the double-flow system with heat recovery is amplified.

To calculate the reduction in energy consumption, it can then be considered that the dwelling has an improved insulation because of the heat recovery from the foul air and the boiler has a better efficiency owing to the heat recovery from the burnt gases.

If we consider the previous example with a gas-fired heating sys-

tem and an initial coefficient before heat recovery,
G_i = 1.2 watt/m3° C.

a) Before recovery

. Annual requirement of the dwelling, B_i :

$$B_i(kWh) = \frac{G_i \times V}{1\ 000} \times DH(18 - \frac{3}{G_i})$$

With the free interior and solar heat gains evaluated at 3 watts/m3 and the average temperature taken into consideration in the dwelling being 18° C :

$$B_i = \frac{1,2 \times 250}{1\ 000} \times DH(15,5) =$$

$$\frac{1,2 \times 250 \times 49\ 136}{1\ 000} = 14\ 740\ kWh.$$

. Effective energy to be generated by the boiler, E_{ui} : if R_d is the efficiency of the distribution which allows for the losses in the piping, regulation system, etc...

$$E_{ui} = \frac{B_i}{R_d}$$

When R_d = 90 %

$$E_{ui} = \frac{14\ 740}{0,9} = 16\ 380\ kWh.$$

. Initial annual consumption, C_i :

$C_i = \frac{E_{ui}}{R_i}$, with R_i the average efficiency on P.C.I. of the boiler during a heating season.

For R_i = 80 % (efficient boiler) :

$$\boxed{C_i = \frac{16\ 380}{0,8} = 20\ 480\ kWh}$$

b) After heat recovery

. Heat loss coefficient, G_r :

$$G_r = 1,2 - \frac{0,34 \times 165 \times 0,7}{250}$$

1,04 watts/m3° C.

. Annual requirements of dwelling, B_r :

$$B_r = \frac{G_r \times V}{1\ 000} \times DH(18 - \frac{3}{G_r})$$

$$B_r = \frac{1{,}04 \times 250}{1\ 000} \times DH(15{,}1)$$

$$= \frac{1{,}04 \times 250}{1\ 000} \times 46\ 987 \simeq 12\ 220 \text{ kWh.}$$

. Effective energy to be supplied by boiler, E_{ur} :

$$E_{ur} = \frac{12\ 220}{0{,}9} \simeq 13\ 580 \text{ kWh}$$

. Annual consumption, C_r

If it is accepted that the perceptible heat losses of high efficiency are only due to the evacuation of hot burnt gases, the new efficiency after heat recovery : $R_r = R_i + (1 - R_i)\varepsilon$, with ε the efficiency of the heat recovery. In the case considered :

$$R_r = 0{,}8 + 0{,}2 \times 0{,}7 = 0{,}94 \quad \text{i.e. } 94\ \%$$

and $C_r = \frac{13\ 580}{0{,}94} = 14\ 450$ kWh.

The saving in gas consumption figures can therefore attain 6 000 kWh, or approximately 30 %.

The anticipated gains from heat recovery are extremely high. They can be obtained without reducing the service facilities offered to the users and the savings thus envisaged are less dependent on their behaviour and the exterior conditions.

Isn't it better to undertake this approach rather than to encourage solutions with very uncertain results ?

6. EXTRACTION FLOW RATES

In kitchens, the minimum flow rates specified by the draft regulations under normal or accelerated ventilation conditions appear to meet the objectives in these rooms.

1 room	2 R	3 R	4 R	5 R and more
20-75 m3/h	30-90 m3/h	45-105 m3/h	45-120 m3/h	45-135 m3/h

In shower rooms, we consider that the occupants should be able to obtain a flow rate of 30 m3/h regardless of the number of main rooms in the dwelling concerned and be able of reducing the rate to 15 m3/h in small dwellings or in dwellings comprising numerous shower rooms. The tolerance of the draft regulations which permit an adjustment of the flow rate to even lower values should, in our opinion, only be taken advantage of if its use is automatically limited to short sequences so as to temporarily increase the ventilation in the kitchen during peak hours.

. In toilets, the requirements are thoroughly perceived and the ventilation can be temporary. The specifications of the draft regulations appear adequate.

The extraction flow rates must be capable of attaining 15 m3/h or 30 m3/h according to the number of main rooms and toilets in the relevant dwelling.

7. SUPPLY FLOW RATES

. In bedrooms, the ventilation installations should not permit actual flow rates of less than 20 m3/h, except in the case of an air transfer in favour of the living room and which is automatically limited to a few hours. During the night, the quality of the air slowly degrades in the bedrooms and the sleeping occupants are not conscious of the fact and therefore do not take steps to modify the ventilation. The overall minimum ventilation rate must therefore ensure air changes in these rooms which generally prevent conditions favourable to the development of condensation or mildew during the heating season. With a flow rate of 20 m3/h in a bedroom heated to 18° C, these bad conditions will not occur more than 10 % of the nights ; but, if the bedroom is only heated to 16° C, which is a temperature often selected for energy saving reasons, the third of the nights during the heating season are affected and, during these periods, the relative humidity can be higher than 85 %.

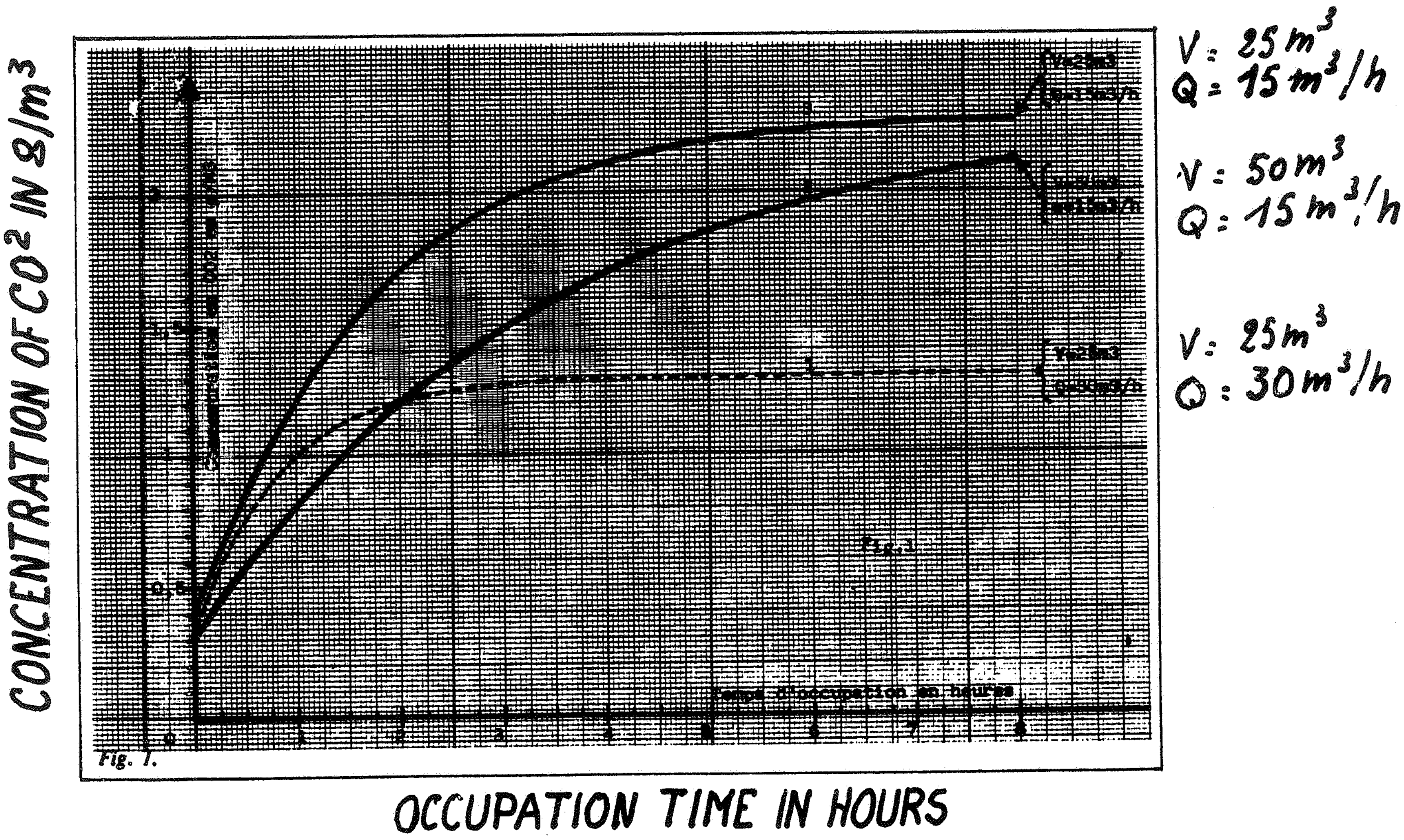
. In living rooms, the polluting emissions from each individual are greater than those encountered in the bedrooms when the occupants are sleeping. In addition, these rooms are intended to accept all the occupants at the same time. These considerations could therefore justify high ventilation rates in the biggest dwellings but the periods of intensive occupation are generally short and the inertia of high volume living rooms enables a fraction of the pollution to be temporarily absorbed. During these same periods, the interior doors are open and the living rooms partially benefit from the air from the unoccupied bedrooms which flows towards the service rooms through the corridors and entrances. The living rooms of small dwellings are less occupied but only slightly, if at all, benefit from the ventilation of other main rooms during the day.

On account of these observations, we feel that the occupants should be able to obtain a minimum overall flow rate of at least 30 m3/h in the living rooms of dwellings with one or two main rooms and, at least, 40 m3/h in the living rooms of other dwellings.

t(°C)	ZONE A		ZONE B		ZONE C	
	F	DH(t)	F	DH(t)	F	DH(t)
− 10	24	65	13	26	0	0
− 9	38	96	23	44	0	0
− 8	64	147	38	74	0	0
− 7	103	230	60	123	2	1
− 6	159	362	87	197	5	5
− 5	232	557	119	300	11	13
− 4	326	836	163	441	23	30
− 3	447	1 222	223	634	40	61
− 2	608	1 750	312	901	70	116
− 1	826	2 467	442	1 278	117	210
0	1 095	3 428	622	1 810	186	361
1	1 411	4 681	860	2 551	280	594
2	1 751	6 262	1 130	3 546	402	935
3	2 094	8 184	1 405	4 814	550	1 411
4	2 444	10 453	1 700	6 366	735	2 054
5	2 804	13 077	2 029	8 231	967	2 905
6	3 171	16 065	2 382	10 436	1 236	4 006
7	3 542	19 421	2 748	13 001	1 535	5 392
8	3 896	23 140	3 128	15 939	1 862	7 090
9	4 208	27 192	3 525	19 266	2 213	9 128
10	4 482	31 537	3 915	22 986	2 583	11 526
11	4 719	36 138	4 276	27 081	2 969	14 302
12	4 926	40 960	4 600	31 519	3 363	17 468
13	5 114	45 980	4 876	36 257	3 758	21 028
14	5 273	51 174	5 107	41 248	4 129	24 972
15	5 397	56 508	5 297	46 450	4 447	29 260
16	5 494	61 954	5 447	51 822	4 725	33 846
17	5 571	67 486	5 561	57 326	4 973	38 695
18	5 633	73 088	5 643	62 928	5 185	43 774
19	5 684	78 747	5 700	68 600	5 353	49 042
20	5 730	84 454	5 740	74 320	5 489	54 464

F - frequencies cumulated
DH(t) - degree hours

Table 1



CONCENTRATION OF CO2 IN g/m3
OCCUPATION TIME IN HOURS
V: 25 m3
Q = 15 m3/h
V: 50 m3
Q: 15 m3/h
V: 25 m3
Q: 30 m3/h
Fig. 1.

Figure 1

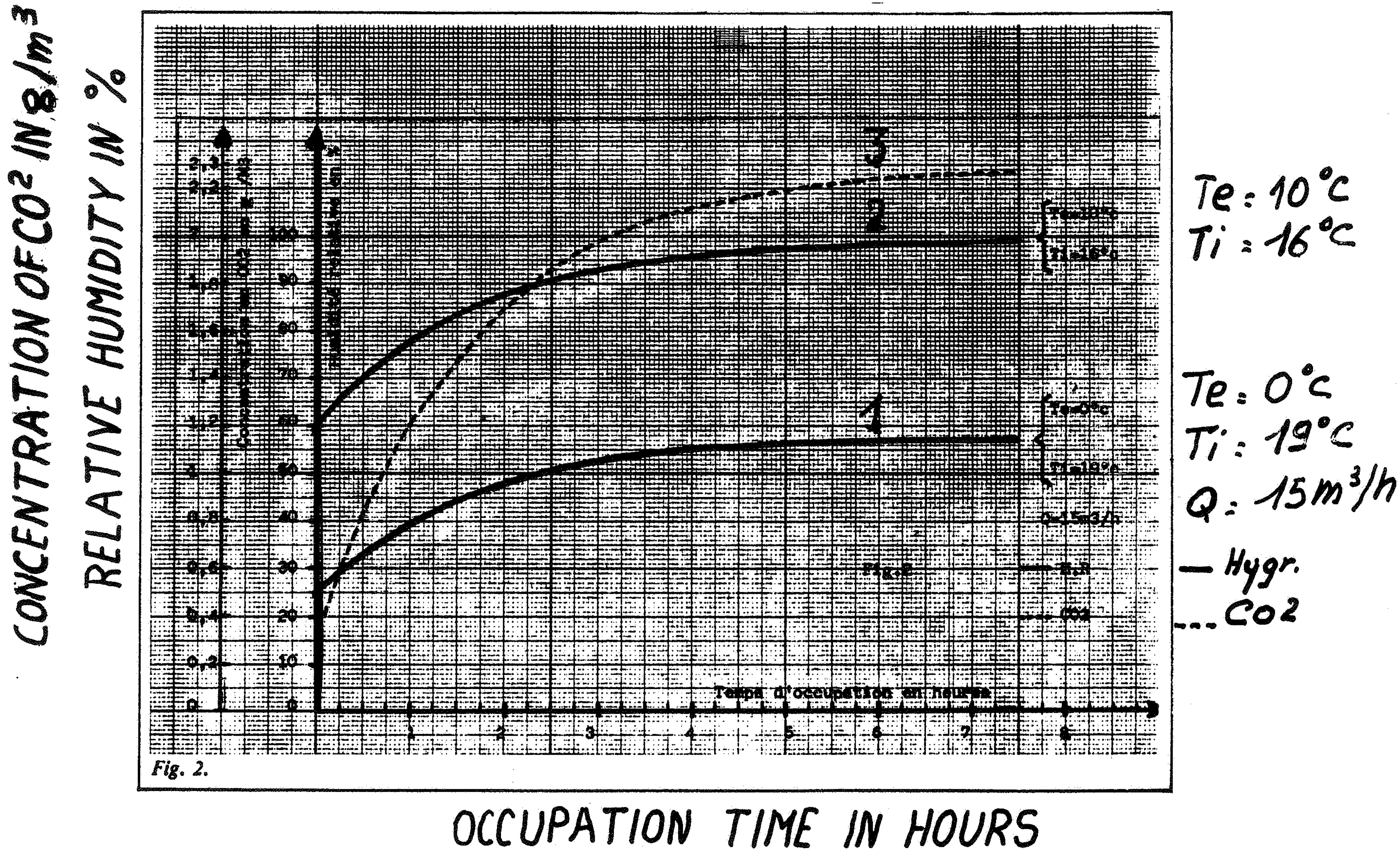
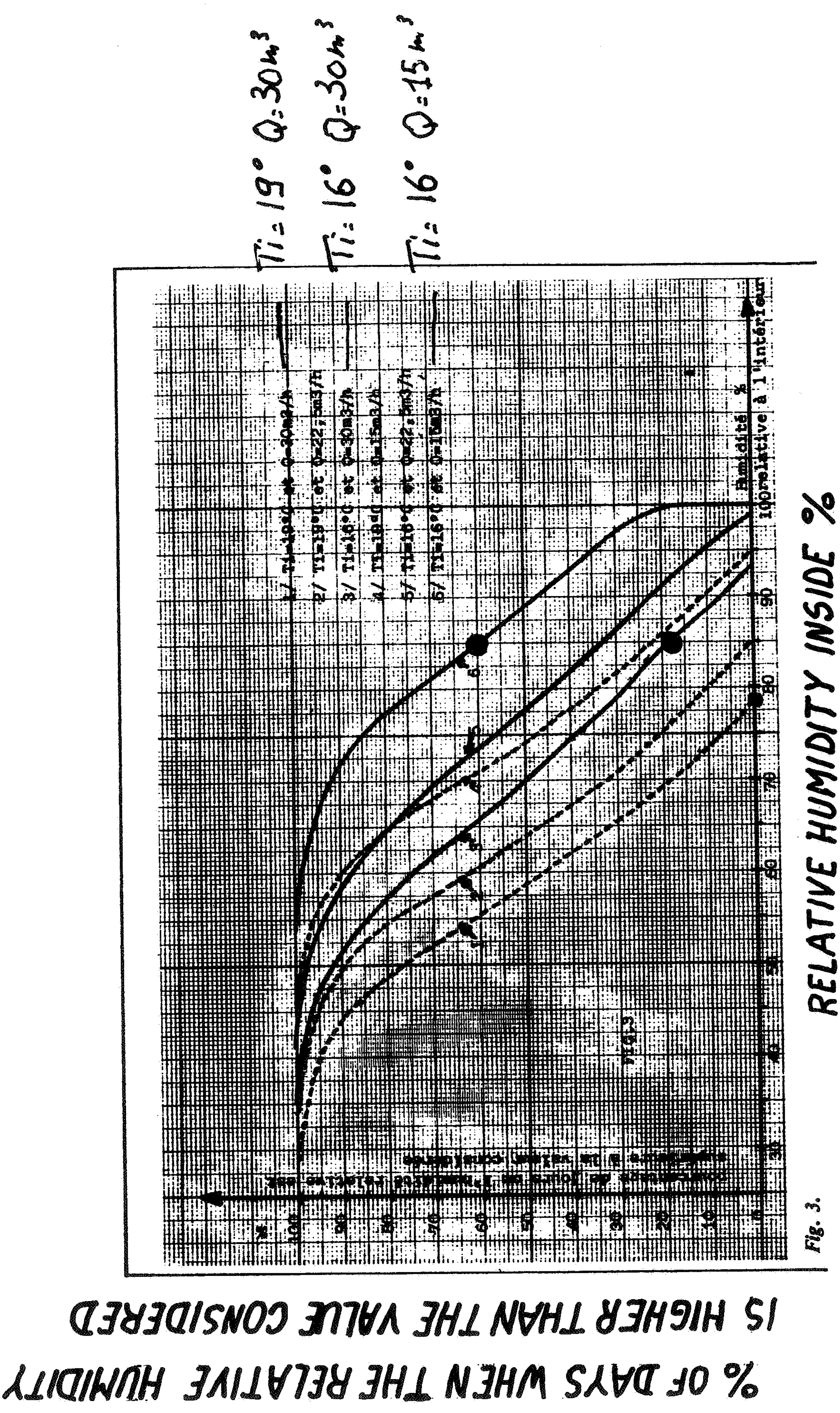
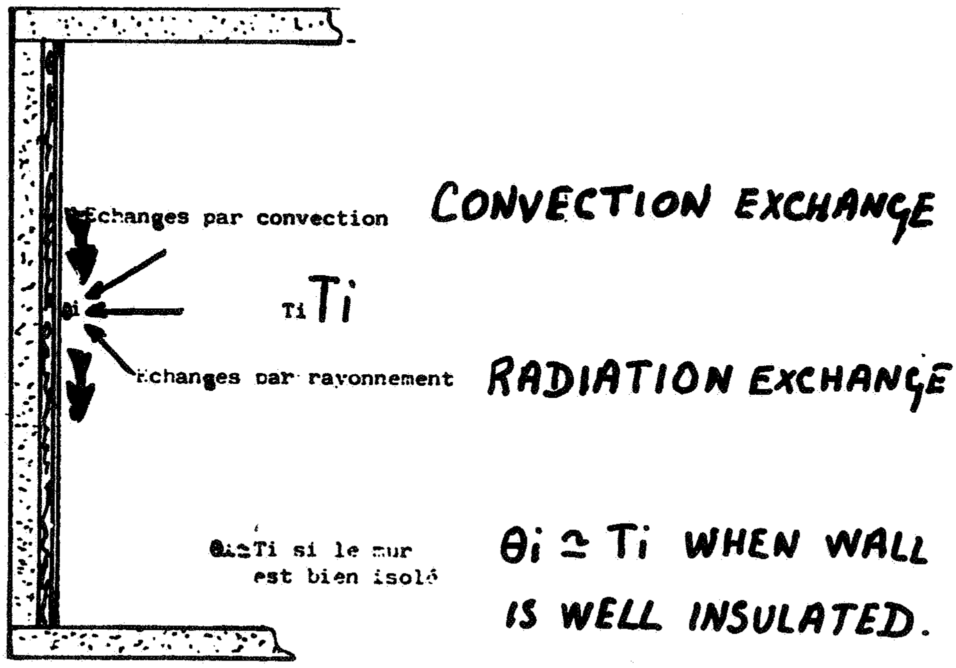

CONCENTRATION OF CO² IN g/m³
RELATIVE HUMIDITY IN %
OCCUPATION TIME IN HOURS
Te : 10 °C
Ti : 16 °C
Te : 0 °C
Ti : 19 °C
Q : 15 m³/h
— Hygr.
--- Co2
1
2
3
Fig. 2.

Figure 2

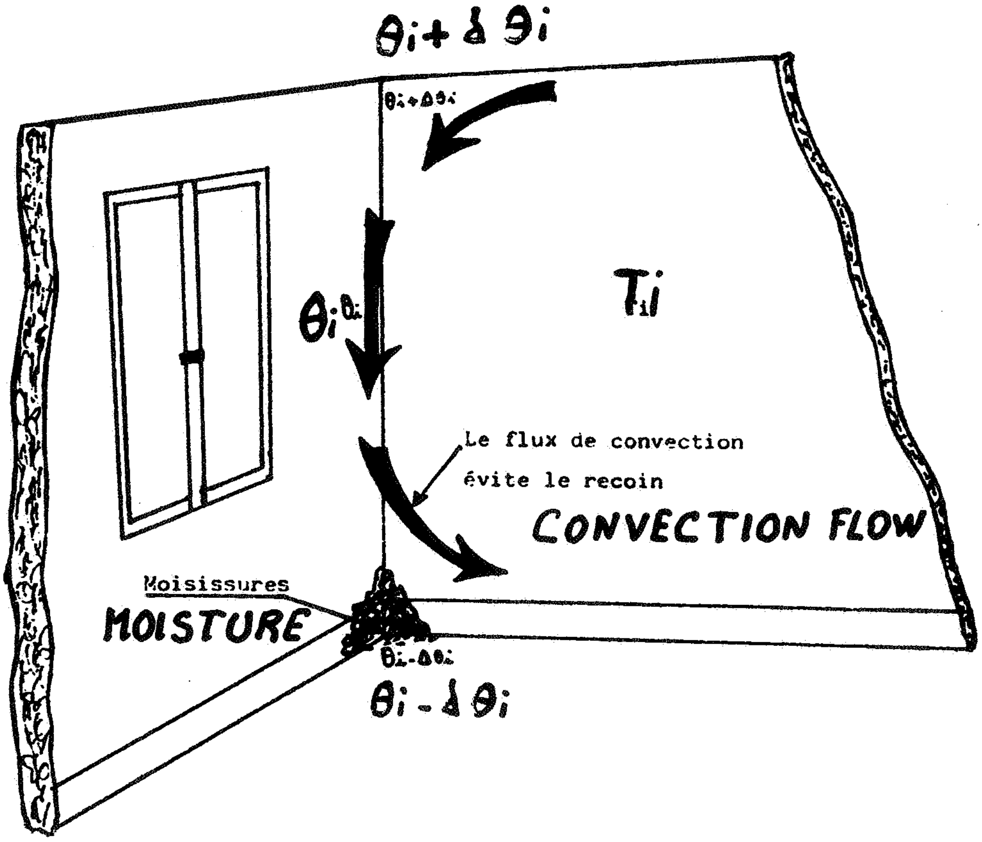


Ti=19° Q=30m³
Ti=16° Q=30m³
Ti=16° Q=15m³
RELATIVE HUMIDITY INSIDE %
% OF DAYS WHEN THE RELATIVE HUMIDITY
IS HIGHER THAN THE VALUE CONSIDERED
Humidité %
relative à l'intérieur
Fig. 3.

Figure 3



Echanges par convection
CONVECTION EXCHANGE
Ti
Ti
θi
Echanges par rayonnement
RADIATION EXCHANGE
θi≃Ti si le mur
est bien isolé
θi ≃ Ti WHEN WALL
IS WELL INSULATED.



θi+Δθi
θi+Δθi
θi
Ti
Le flux de convection
évite le recoin
CONVECTION FLOW
Moisissures
MOISTURE
θi-Δθi
θi-Δθi

Figure 4

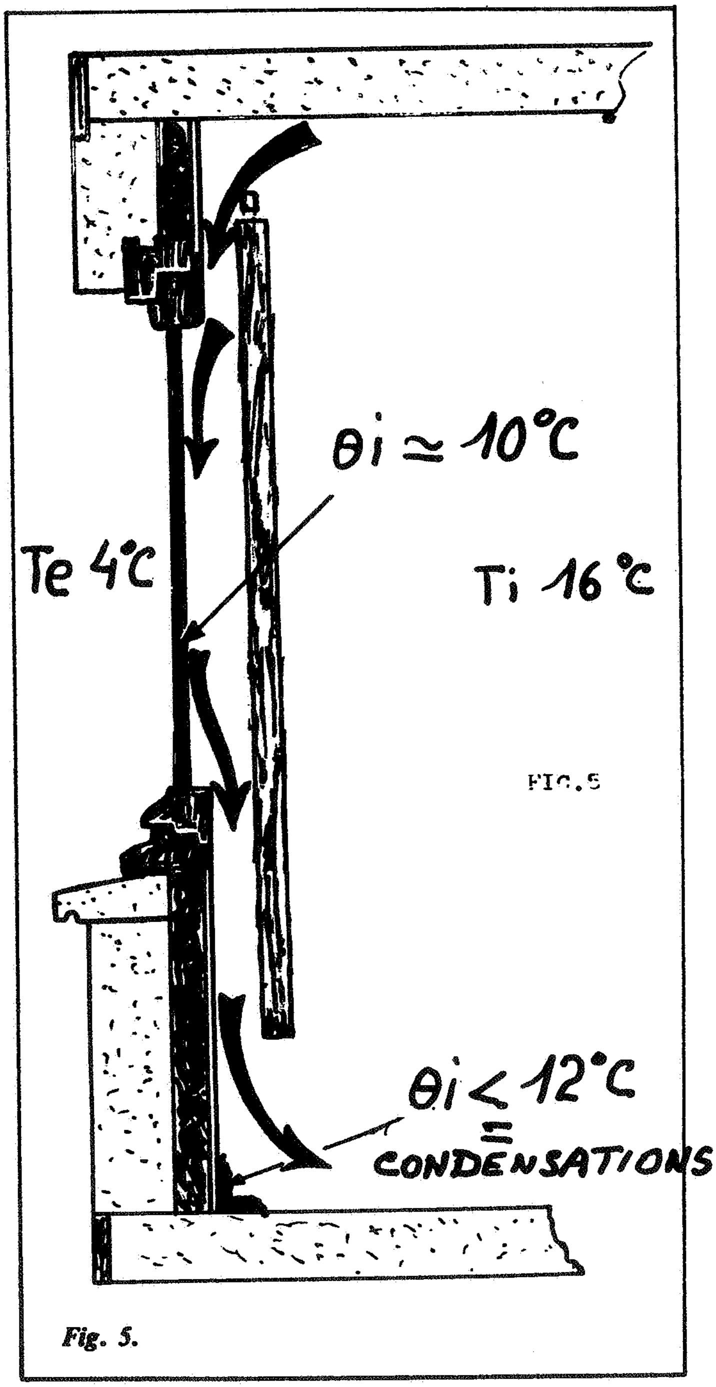


Figure 5

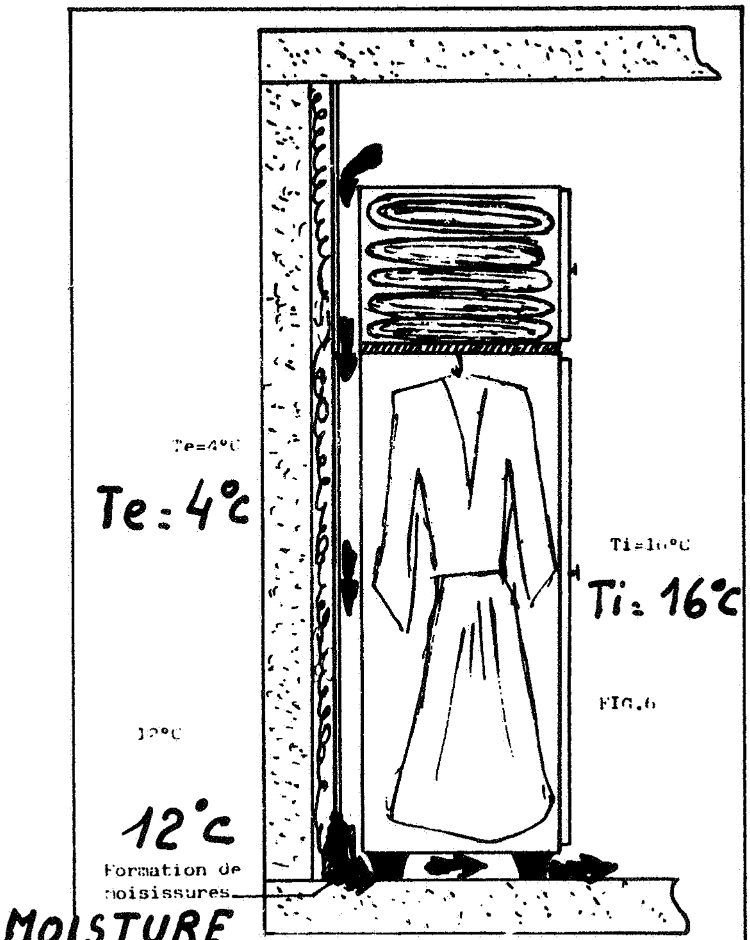


Fig. 6.

Figure 6

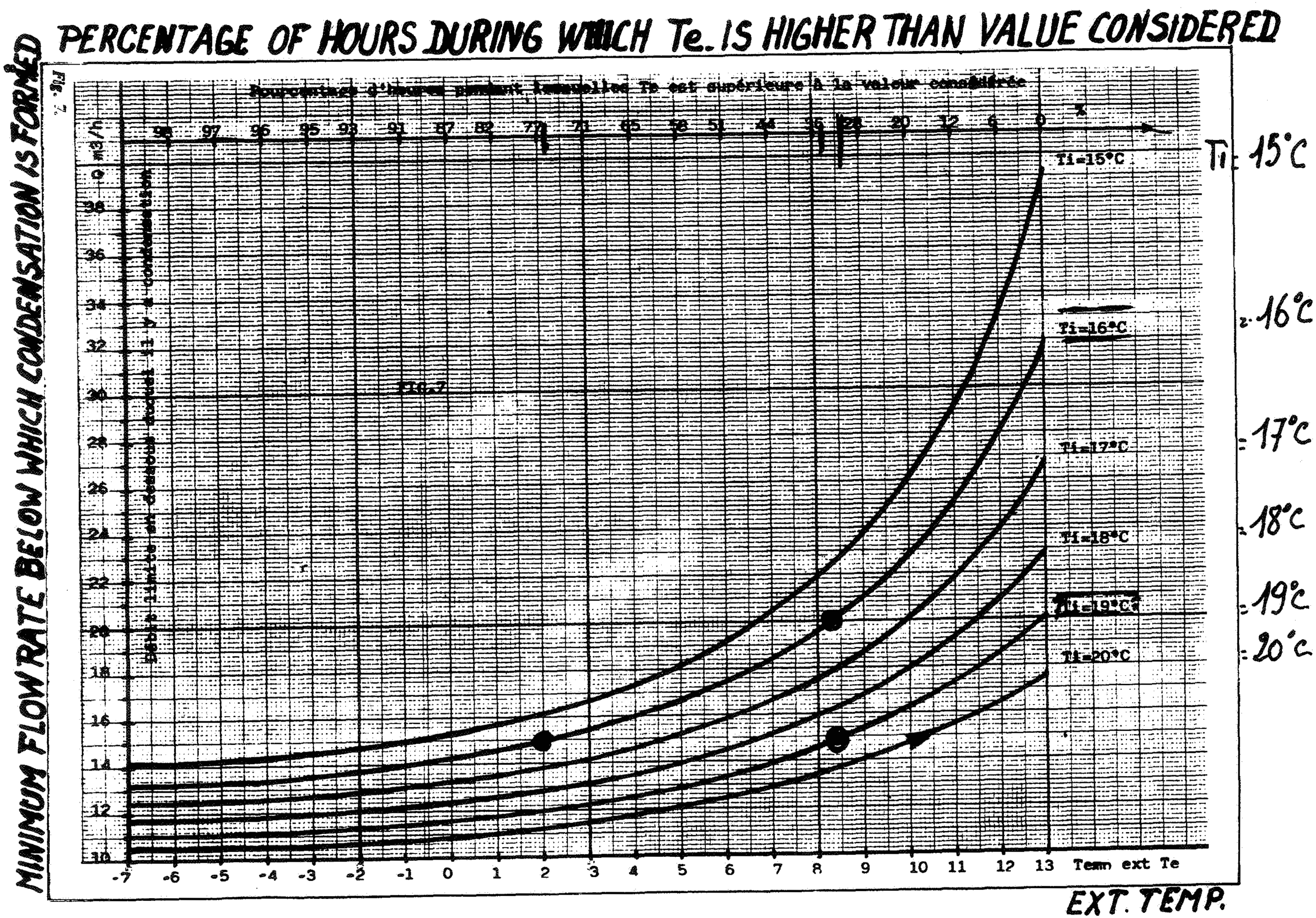

PERCENTAGE OF HOURS DURING WHICH Te. IS HIGHER THAN VALUE CONSIDERED
MINIMUM FLOW RATE BELOW WHICH CONDENSATION IS FORMED
Q m3/h
%
Ti: 15°C
16°C
17°C
18°C
19°C
20°C
Ti=15°C
Ti=16°C
Ti=17°C
Ti=18°C
Ti=19°C
Ti=20°C
FIG.7
Temp ext Te
EXT. TEMP.

Figure 7

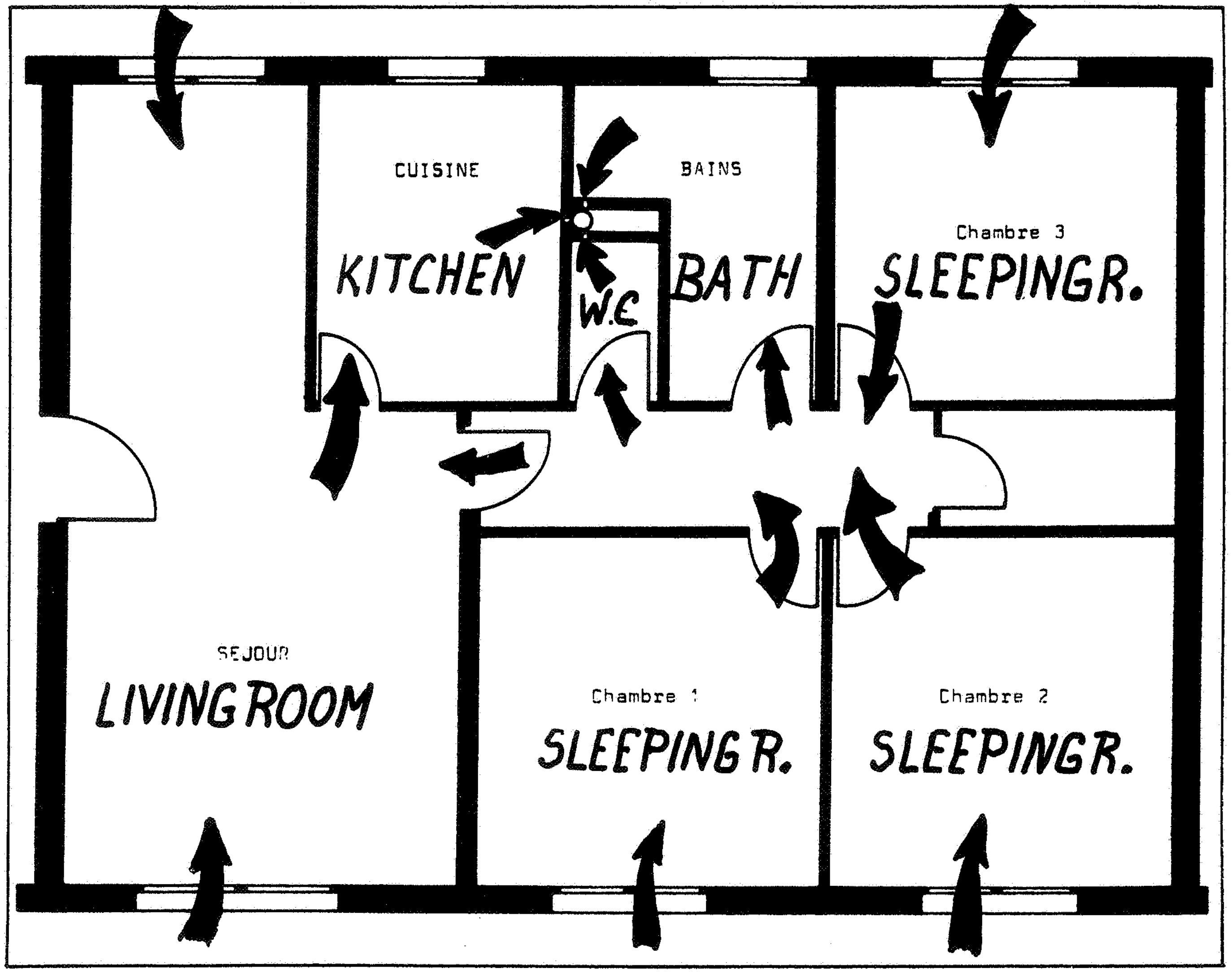
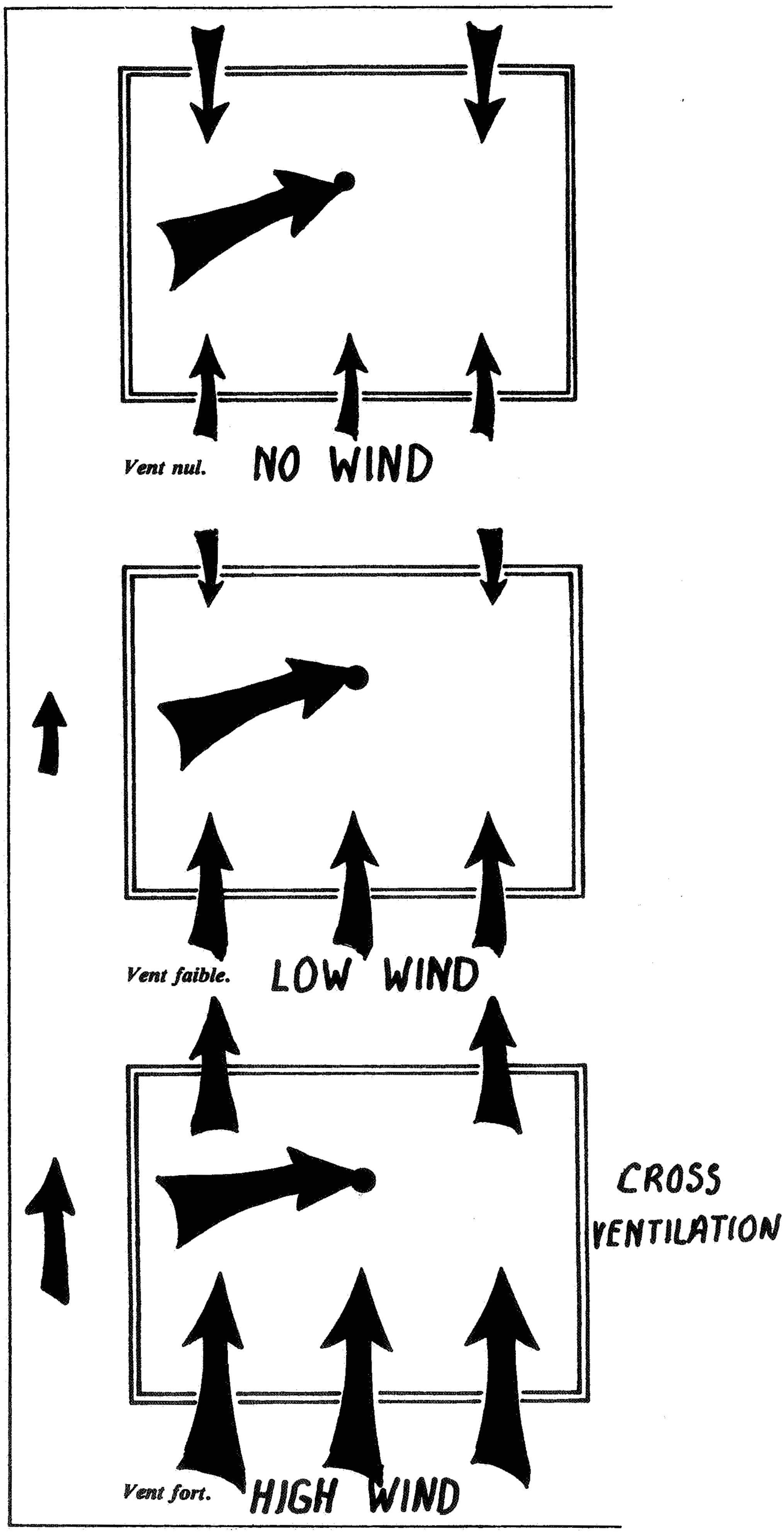
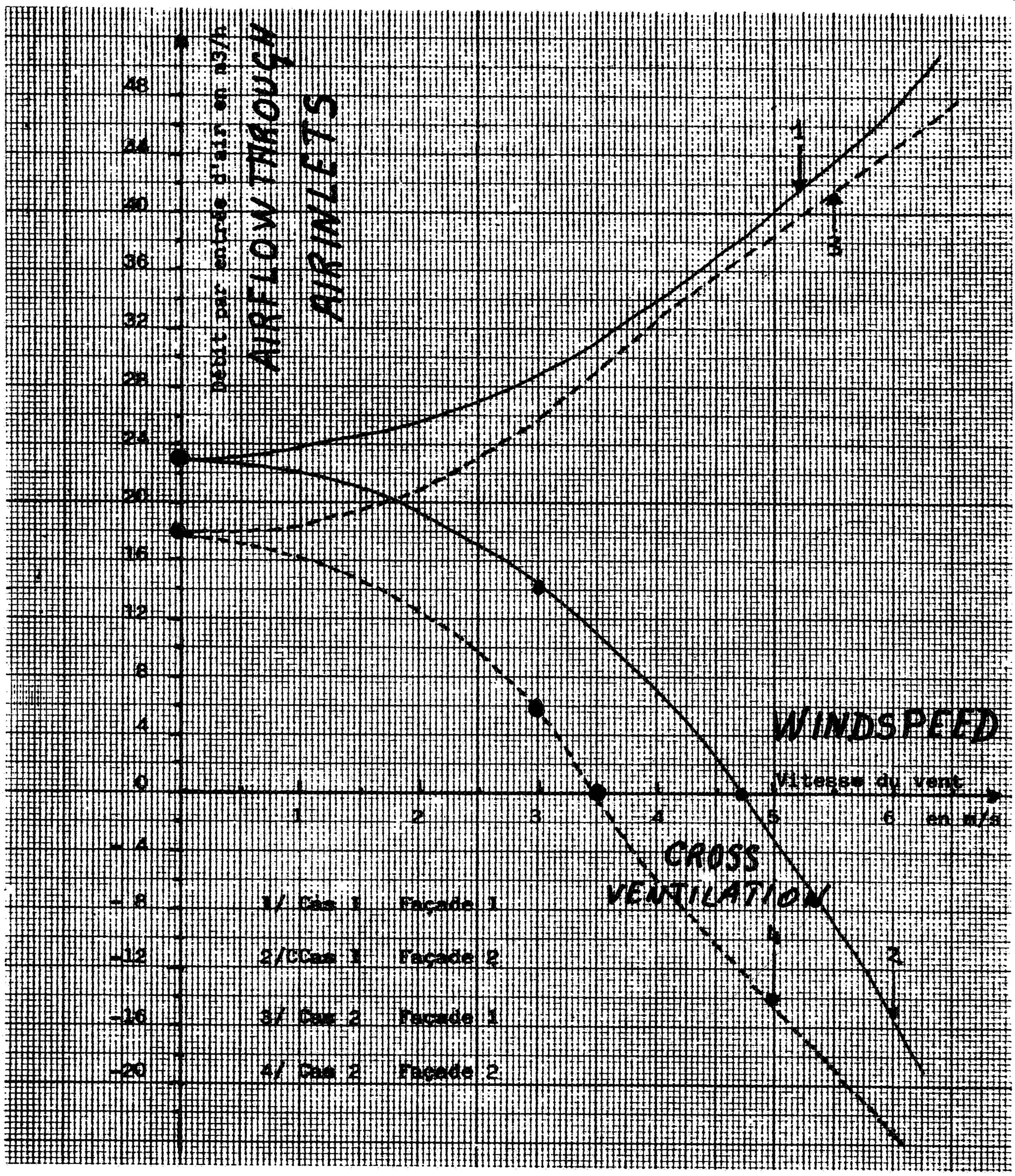

CUISINE
KITCHEN
W.C
BAINS
BATH
Chambre 3
SLEEPINGR.
SEJOUR
LIVINGROOM
Chambre 1
SLEEPINGR.
Chambre 2
SLEEPINGR.

Figure 8



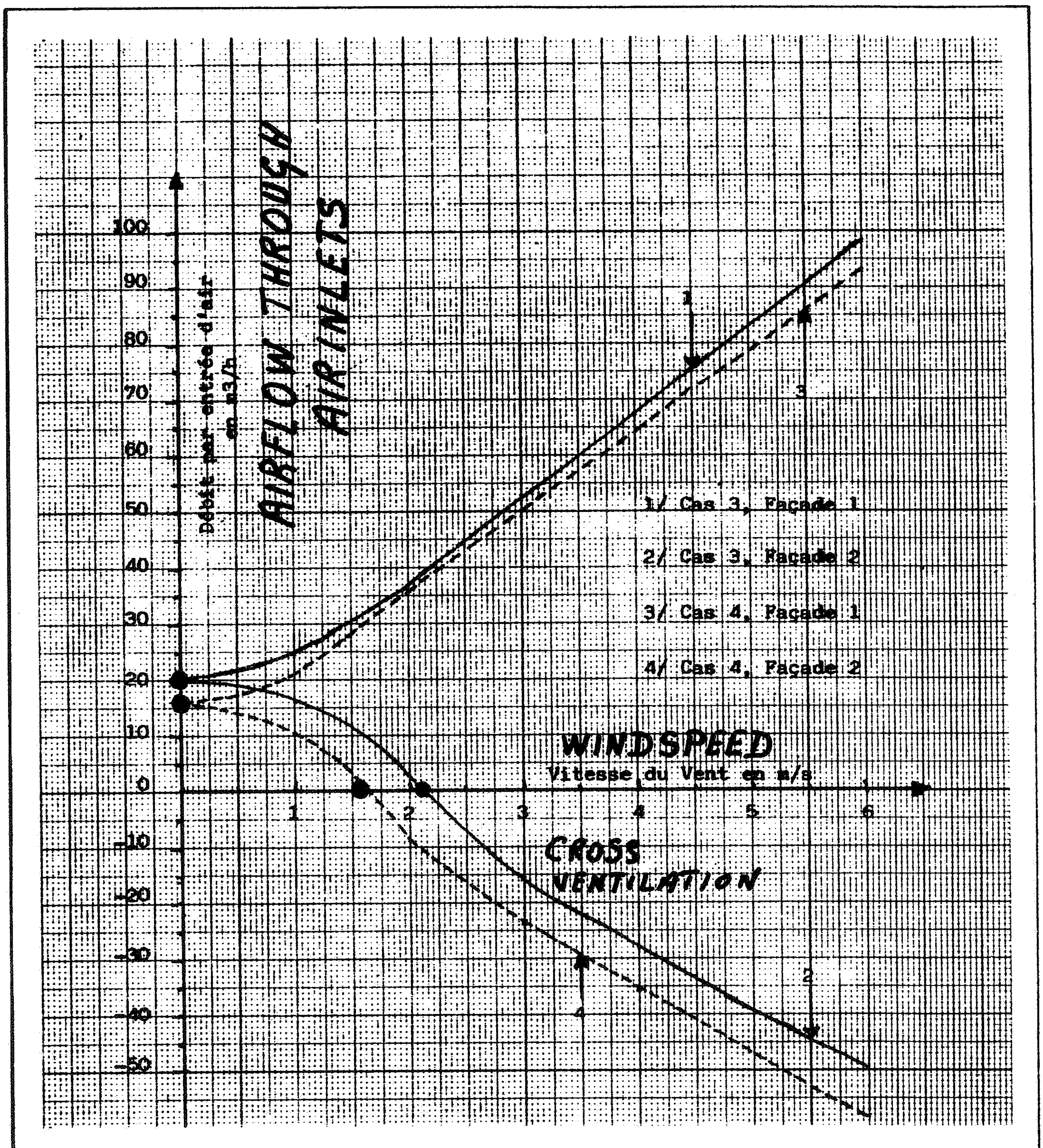
Figures 9a - 9b - 9c



Influence du vent en extraction mécanique.

WIND INFLUENCE WITH MECHANICAL VENTILATION

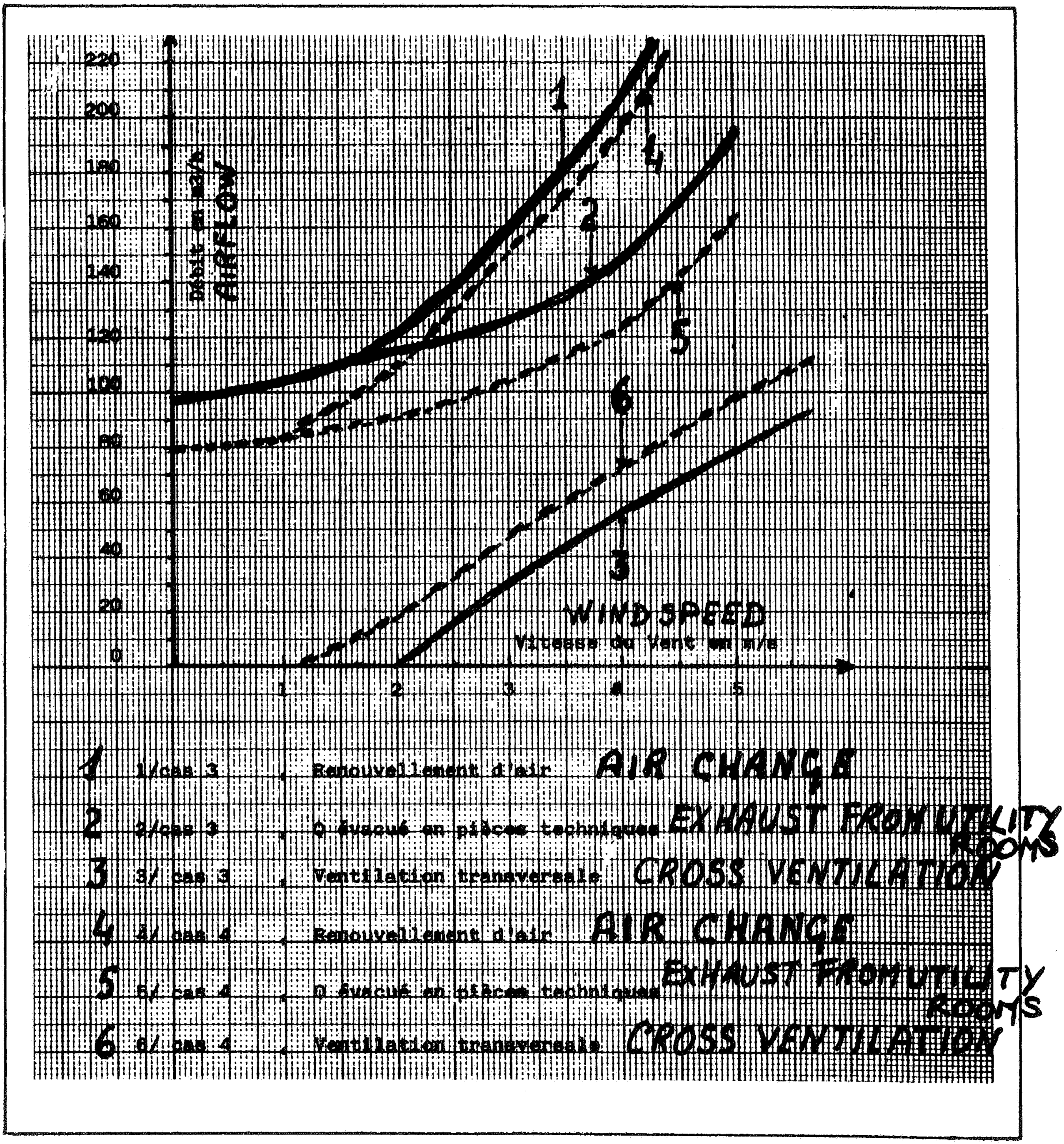
Figure 10



Influence du vent en tirage naturel.

WIND INFLUENCE WITH NATURAL DRAUGHT

Figure 11



Débit en m3/h
AIRFLOW
220
200
180
160
140
120
100
80
60
40
20
0
WIND SPEED
Vitesse du vent en m/s
1
2
3
4
5
1
2
3
4
5
6
1 1/cas 3 Renouvellement d'air AIR CHANGE
2 2/cas 3 Q évacué en pièces techniques EXHAUST FROM UTILITY ROOMS
3 3/ cas 3 Ventilation transversale CROSS VENTILATION
4 4/ cas 4 Renouvellement d'air AIR CHANGE
5 5/ cas 4 Q évacué en pièces techniques EXHAUST FROM UTILITY ROOMS
6 6/ cas 4 Ventilation transversale CROSS VENTILATION

Figure 12

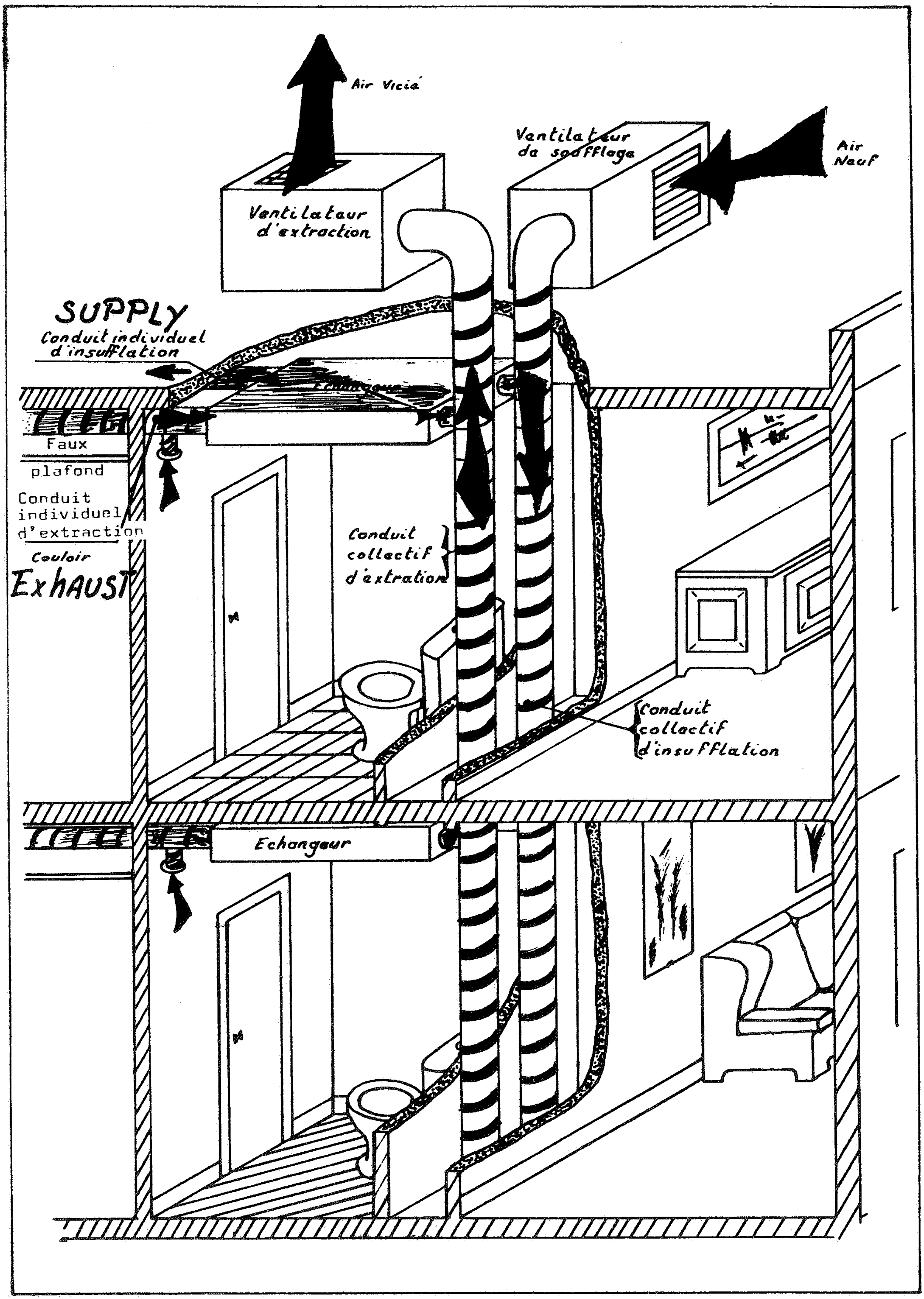

Air Vicié
Ventilateur de soufflage
Air Neuf
Ventilataur d'extraction
SUPPLY
Conduit individuel d'insufflation
Faux
plafond
Conduit
individuel
d'extraction
Couloir
Exhaust
Conduit collectif d'extration
Conduit collectif d'insufflation
Echangeur

Figure 13

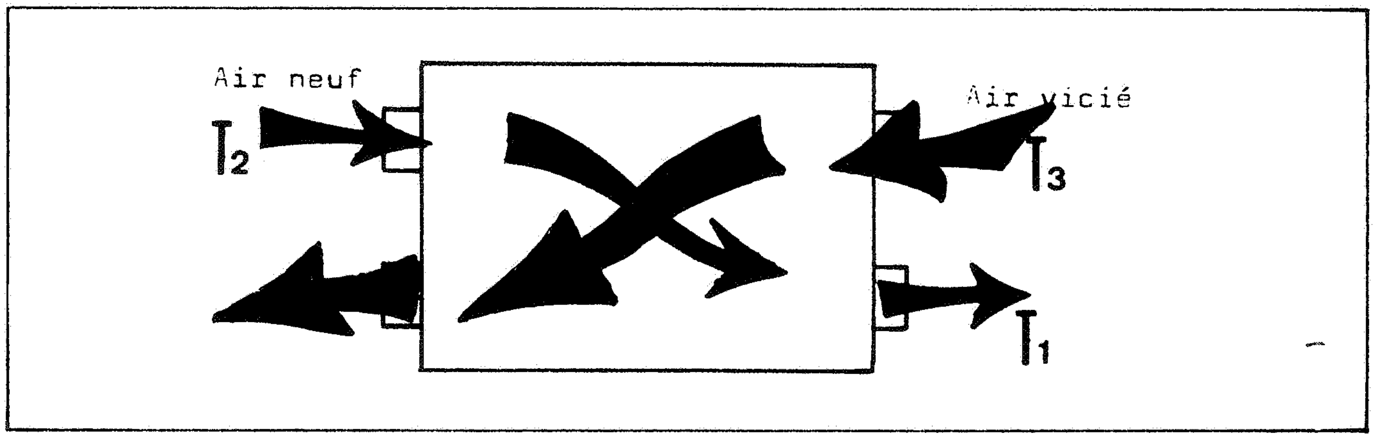


Figure 14

ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER: F

A METHOD TO ASSESS THE HEALTH AND COMFORT CHANGES AMONG TENANTS AFTER DRAUGHT PROOFING OF THEIR FLATS

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INTRODUCTION

The aim of the present study is to measure the possible health effects among tenants after certain characteristic energy conservation measures had been taken in their dwellings. In addition to health effects, changes in sensation of comfort/discomfort related to indoor climate exposure in accordance with the WHO-definition[1] are also included.

The study is part of the number of projects, which the Department of Energy, Copenhagen has given the Institute of Hygiene, University of Aarhus, comprising indoor pollutant source control[2] as well as changes in house dust mite populations related to moisture changes in retrofitted dwellings[3].

The concept of combining different methodological studies like this is based on the experience from other fields of environmental health studies in that they generally should include both field measurements and observational health studies, as well as controlled exposure studies, to be conclusive. This presentation should be regarded as interim information concerning a particular study in progress. The final report is not due until 1st February 1983.

BACKGROUND

The specific Danish background of the health studies is the so-called Energy Plan 76, which claims that from 1975 to 1985 the gross energy consumption for building climatization should be reduced by approximately 25% in the existing building stock.

This goal could be achieved in three possible ways:

1. More efficient heat production,

2. alternative energy supply (solar heat, heating pumps, etc.),

   and last and most important in a climate having about 3000 degree days in the officially designated 227 days heating season,

3. reduced heat consumption in buildings by improved insulation and reduced uncontrolled air infiltration.

This has been described in more detail in a 371 page publication[4] in which 4½ pages describe the possible adverse effects of energy saving measures in buildings on the building itself, such as damage from frost action, boiler corrosion, noise and vibration from installations, increased danger in case of fire, dampness and condensation and related risk of mould and fungus growth. Another 1½ pages in this book describe the possible adverse effects to the indoor climate under the following headings:

- indoor air humidity
- irritating gases
- static electricity
- aero-allergens

The conclusions were, however, that more had to be known about the possible negative or positive affects on human beings caused by those changes in the building following energy conservation measures.

It is already known that the indoor climate factors are very closely interacting, but we know very little about the effects resulting from moderate exposure conditions such as those occurring in the domestic environment as distinct from those effects related to occupational exposure. Therefore, this study was designed on the basis of collecting written information from single individuals about their sensation of health, comfort and physical wellbeing related to the indoor environment. The idea was to obtain this information both before and several times after energy conservation measures had taken place.

The study was designed as an observational investigation with two groups; a study group and a corresponding control group not exposed to environment changes in their homes other than those which normally occur throughout the seasons of the year. This is what is called a concurrent prospective study in epidemiology.

The general concept of the prospective study is relatively simple. A sample of the normal population is selected and information is obtained to determine which persons either have or have not a particular characteristic, e.g. energy conservation measures carried out, that is believed to be related to changes in health and comfort, both positive and negative. These individuals are followed for a period of time to observe who developed changes and to what degree they occur.

In this case, the necessary data for assessing these developments have been obtained from the tenants by monthly questionnaires, four times in all, once before changes took place and three times after changes had been carried out; more precisely - August 1981, December 1981, January 1982 and February 1982. In the control group, similar questionnaires were answered at the same time but, as mentioned, previously no building changes took place there.

However, the main problem to consider has been how to measure changes in health in a specially exposed population within a relatively short period of time and compare the findings with those of the normal population.

Our study population has been specially exposed to a supposed environment change in their homes caused by energy conservation measures which, in this particular case, were replacement of single glass windows with double glass windows and sealing of joints aiming to improve insulation and to reduce uncontrolled air infiltration.

The health of the population is normally measured on the basis of some well-defined and well-recorded input data, such as death rates and prevalence of specific diseases related to certain demographic characteristics like age, sex, race or ethic group. We could not expect to make any use of this kind of data with regard to the expected acute or sub-acute health effect of indoor climate changes.

Our target has, for that reason, been the field of health between diagnosed and medically treated illness and feelings of non-optimal health condition as reflected by certain typical symptoms such as pains, cough, irritation in mucous membranes and eyes and the evidence of some normally not medically treated diseases, such as the common cold and certain other virus infections.

We know from a more general health survey carried out in a suburban city population outside Copenhagen[5] some years ago, that about 55% of the 40-year old population are faced with, or feel, some kind of health problem during the year with an increased percentage in higher age groups. The basic problem in the study has been to make it large enough in scale to be sure that no random effects among a small study population would lead to fallacy in the conclusions.

Each questionnaire had a total of 41 questions distributed within the following main groups:

a. Personal characteristics (age, sex, years of residency, smoking habits).

b. Flat characteristics (window types).

c. Occupancy and use of flat (number of residents and age, average occupancy hours, smoking, washing, cooking, window opening, domestic animals).

d. Sensation of comfort or discomfort related to partly thermal, atmospheric and acoustic environment.

e. Somatic symptoms (pain or illness without medical treatment).

f. Chronic diseases or illness with medical treatment.

g. Physical indications (observation of fungi, mould or condensation).

With an estimated maximum of 3000 respondents and 4 surveys, it was realised that both mailing procedures and data handling would be facilitated if an optical character recognition (OCR) procedure was adopted to read the questionnaires directly to the database.

CONCLUDING REMARKS

The preliminary results of this study show that it would be desirable to conduct similar studies under different climatic conditions and for other types of building, but with the same methodology so that the studies would be comparable.

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Discussion

DISCUSSION

Session 1

Monday afternoon - 20th September 1982

Chairman: Peter J Jackman (U.K.)

Paper 2 : 'Use of natural ventilation' presented by Geoff Brundrett (UK)

P.F. Collet (Denmark) — How do you come to the conclusion that opening the windows doubled the air change rate? Our studies show that in occupied dwellings an air change rate of up to 5 times that measured in an unoccupied dwelling is observed (with windows and external doors closed).

G. Brundrett (U.K.) — *The figures were arrived at purely by calculation.*

W.F. de Gids (Holland) — Was wind direction used as a variable?

G. Brundrett (U.K.) — *Wind direction was not examined as a potential factor.*

W.F. de Gids (Holland) — How similar is similar in terms of airtightness?

G. Brundrett (U.K.) — *Each house was pressure tested and the results showed reasonable uniformity (Fig. D1).*

D. Etheridge (U.K.) — It is stated that the ventilation loss is based on bedroom temperature. What is the justification for this, bearing in mind that wind effects seem important?

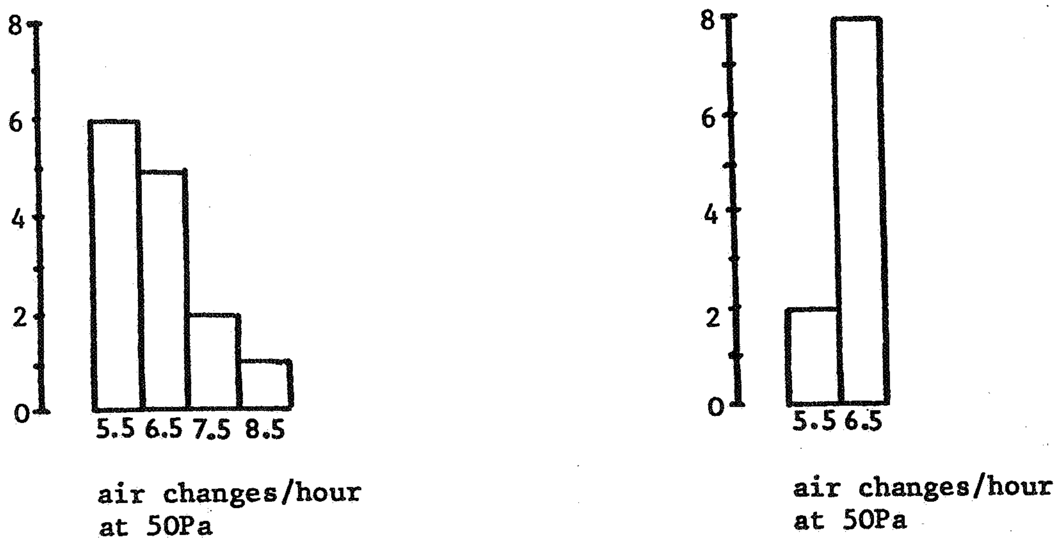
If mean house temperature has been taken, how much would the ventilation heat loss have been increased?

G. Brundrett (U.K.) — *Bedroom windows were the ones most often open. The air was assumed to leave the house through this route due to the combination of stack effect and wind pressure.*

The ventilation energy loss was calculated from the estimated total energy supplied to the house less the fabric heat loss. The energy loss would be independent of the bedroom temperature. Bedroom temperature was used to convert the ventilation energy into air changes per hour. The use of the house temperature instead of the bedroom temperature in this calculation would have lowered the air change rate by approximately 15%.

D. Harrje (U.S.A.) — You mentioned that windows were not necessarily closed fully. Our past studies have indicated that, depending on the weather period - mid-winter versus spring for example, windows would not be closed with the same precision.

Figure D1



14 terraced houses

10 detached houses

Pressure tests applied to the 24 dwellings

Please comment further on tightness over time and window use and what constituted an "open" window, i.e. how far open?

G. Brundrett (U.K.)

Pressurisation tests were carried out on three houses six months from the first tests. The first two of these houses had been occupied during the winter, while the third one was a control house running heated but unoccupied. These results show that the houses were practically the same as their first test.

Table D1

House	September	March
1 occupied over winter	5.9	5.6
2 occupied over winter	6.3	6.0
3 unoccupied	6.6	6.6

Our window reporter believed she could tell if a window was slightly open. In recording an open window, no distinction was made between "slightly" or "fully" open. The only choice was "open" or "closed".

PAPER 3 : 'Variations in householders' window opening patterns' presented by Gillian Conan (Republic of Ireland)

R. Gale (U.K.)

Was there any correlation between window opening and the type of heating pattern used? It is less significant for heat loss if a window is open when the heating system is used intermittently.

G. Conan (Ireland)

No. When divided into three groups according to window opening propensity, there was no significant correlation between reported hours of central heating use and window opening. Most householders used the heating system intermittently.

R. Gale (U.K.)

I have a theory that people open windows for good reasons and then forget they have opened them. Would you like to comment?

G. Conan (Ireland)

I agree.

D. Harrje (U.S.A.)

What is the significance of the statement that there is a smaller standard deviation for an individual home and their habits compared to that of the larger number of houses, yet the correlation coefficient between the larger sample and the weather was better than that between the weather and the single house?

G. Conan (Ireland)	*The smaller proportions of variance explained refer to regression analyses of individual householders' window opening from social or demographic variables and not from weather parameters.*
M. Masoero (Italy)	Did you feel any significant dependence of window opening on household composition or occupants' age?
G. Conan (Ireland)	*Yes. In general 24.6% of the variance in window opening is accounted for by the number of openable windows and the number of household occupants. However, when window opening is looked at separately for three life-cycle groups, different proportions of variance are explained.*

Additional Paper A	'Ventilation patterns of windows and adjustable natural ventilation systems' presented by R. Daler (Germany)
W.F. de Gids (Holland)	Did you analyse the measured data against meteorological data?
R. Daler (Germany)	*Yes. The meteorological data consisted of temperature differences, wind velocity and wind direction.*
D. Etheridge (U.K.)	Does Figure 1 show the position of the anemometer?
R. Daler (Germany)	*Yes.*
D. Etheridge (U.K.)	Is the test house exposed to the wind?
R. Daler (Germany)	*Yes, completed exposed.*
D. Etheridge (U.K.)	Is there any information about the pressure distribution generated by the wind?
R. Daler (Germany)	*We have measured the pressure at different positions on the facade. The pressure varied strongly with both time and location, on a very short time scale due to turbulence.*

Session 2

Tuesday morning - 21st September 1982

Chairman: Willem de Gids (Holland)

Paper 4 : 'Avoiding condensation and mould growth in existing housing with the minimum energy input', presented by Mike Finbow (UK)

R. Gale (U.K.)

Did you take any account of the porosity of the building materials in arriving at your figures? Even a small change in the percentage moisture content of a brick wall amounts to several kilograms of water. Building materials have different moisture contents in the summer and winter months, and centrally heated houses have very low moisture contents in winter. The building materials themselves absorb peaks in internal moisture concentration and release moisture slowly when the humidity is low.

M. Finbow (U.K.)

I was not able to take account of this during this study, but I hope to extend the simple dynamic analysis to compare, over a daily cycle, the temperature necessary to avoid condensation with the temperatures likely to be achieved due to heating. If the negative difference between the temperatures during the night was cancelled out by the positive difference during the day when the internal temperature exceeded that required for condensation control, then it might be assumed that moisture absorbed by the structure would be evaporated again during the day.

K. Johnson (U.K.)

Similar homes in Liverpool have intermittent heating only and walls never reach equilibrium as on the figures. They remain cold, and this is apparently the main cause of condensation problems. In view of this, the position of any insulation is important. Do you have any comments on the best position for insulation in these conditions?

M. Finbow (U.K.)

Under these conditions one should use, almost certainly, internal insulation so that there is a fast response to the changing conditions.

H. Trethowen (New Zealand)

In a similar (but much smaller) study in New Zealand, the calculations were used to derive a diagnostic rule for the *causes* of indoor moisture problems - the "7^{o}C rule". This can be summarised as follows:

> If there are winter indoor moisture problems and the indoor temperature is
>
> (a) not kept at least 7^{o}C above outdoors, then there is not enough heating, or
>
> (b) kept at least 7^{o}C above outdoors, then there is not enough ventilation, or
>
> (c) too expensive to maintain at 7^{o}C above outdoors, then there is not enough insulation.

This paper seems to indicate something fairly similar. A second result was that insulation of ceilings did not improve condensation or mould growth risk on walls; in fact it marginally increased the risk.

M. Finbow (U.K.) — *In my opinion, insulation should be carried out first. This allows people who cannot afford much energy to achieve higher internal temperatures and, if placed internally, will allow surface temperatures to increase quickly when heat is introduced.*

I suggest that, as various parts of a room are insulated, the area of surface available to remove water vapour from the air by condensation is reduced and the problem is transferred to the remaining uninsulated surfaces. The same argument is also put forward in relation to the introduction of double glazing.

Paper 5 : 'Ventilation rates in relation to emission of gases and vapours from building materials' presented by Lars Mølhave (Denmark)

G. Brundrett (U.K.) — How can the residents know whether their house is contaminated with formaldehyde gas? Can they rely on their sense of smell?

L. Mølhave (Denmark) — *If you mean by "contamination" concentrations exceeding 0.15 mg/m^3 (say in the range 0.15 to 0.25 mg/m^3), only the more sensitive part of a normal population will register symptoms. In practice, chemical measurements are the only way to establish formaldehyde as a cause for complaints.*

Formaldehyde has several interesting properties as an odourant, which makes its odour intensity almost useless as a concentration measure in houses, etc.

P.F. Collet (Denmark) — Do you expect a 50% decrease in emission of formaldehyde from chipboard in houses? In our experience, after 5-8 years we find a residual concentration of 0.2 - 0.4 mg/m^3 which means that the initial concentration could have been around 2 to 5 mg/m^3.

L. Mølhave (Denmark) — *The chipboard you mention is probably from a batch of bad boards, the detailed behaviour of which we do not know.*

P.F. Collet (Denmark) — Is Figure 1 related to the house shown on your diagrams? Do you not have condensation problems with the double glazing?

L. Mølhave (Denmark) — *The condensation has been noticed.*

M. Finbow (U.K.) — Were the particle boards plywood as well as chipboard and to what extent were the boards sealed to prevent the release of formaldehyde gas?

L. Mølhave (Denmark) — *Only particle boards were used (chipboard) and all accessible surfaces were coated by a formaldehyde-absorbing paint.*

D. Grimsrud (U.S.A.) — What variation have you seen in emission rates of particle board samples?

L. Mølhave (Denmark) — *It depends on the factory that manufactured the material. Within the same production line, it is a factor of two but varies by a factor of ten among different factories.*

D. Grimsrud (U.S.A.) — What is the characteristic time for the reduction in emissions from organic materials?

L. Mølhave (Denmark) — *It is of the order of one half in three years.*

M. Sandberg (Sweden) — In your conclusions, you propose that people should ventilate their homes to a greater degree during an initial period to avoid high exposure to formaldehyde. Why cannot the manufacturers ventilate their products more instead, before they are delivered?

L. Mølhave (Denmark) — *The storage time will be too long to be practical and the product will become too expensive. A better way would be to modify the production and the raw materials used.*

Additional Paper F — 'A method to assess the health and comfort changes among tenants after draught proofing of their flats' presented by Gunnar Lundqvist (Denmark)

D. Harrje (U.S.A.) — One comment is directed at the perceived comfort between August and winter conditions. The retrofit versus control sample difference would have been more believable had the preliminary comparison been under similar weather conditions. My question concerns the merits of ear examinations as being indicative of indoor air quality in the school. Is it not true that any low grade infection may be due to home environment, exposure to schoolmates with such problems, etc. thereby possibly clouding any result?

G. Lundqvist (Denmark) — *The comparison between the study group and the control group should be reliable under all circumstances. Complaints of draught and cold feet among 10% of both populations in August can be explained by personal characteristics such as age, presence of chronic disease, etc.*

The health and ear-examination study of children in ten daycare institutions is considered as a multi-variance study, which means that the factors you mentioned, and several others, are included as variables.

M. Finbow (U.K.) — Were you able to measure the air infiltration characteristics of the dwellings before and after the change of windows?

G. Lundqvist (Denmark) — *It has been considered too large a task to determine air infiltration rates in all flats related to the study. Measurements in a few random selected cases will give a level of the physical changes obtained.*

M. Finbow (U.K.) — Was there a greater incidence of reported condensation problems, particularly mould growth, after retrofit?

G. Lundqvist (Denmark) — *There was reported a decreased incidence of condensation occurrence after changing to double-glazed windows, even with other retrofitting at the same time. Mould has not been reported but it must be remembered that the study only covers the first winter season after the changes were made.*

Paper 6 : 'Ventilation and internal air movements for summer and winter conditions' presented by Peter Burberry (U.K.)

D. Harrje (U.S.A.) — Figure 1 indicates that the ventilation slots increase ventilation with increasing wind speed. This contrasts with winter requirements that may well be constant. Have you considered passive devices that could provide a constant ventilation rate?

P. Burberry (U.K.) — *Such devices have been considered but no data is available.*

Paper 7 : 'A comparison of alternate ventilation strategies' presented by David Grimsrud, U.S.A.

P.F. Collet (Denmark) — In respect of alternating the flow of air in the ventilation system, are you aware of the total disaster it will induce in a flat timber roof covered with bituminous felt?

D. Grimsrud (U.S.A.) — *No, but it is noted now.*

P.F. Collet (Denmark) — Has the gadget for measuring air change rate been checked in a realistic situation to see whether it measures the change between rooms, or can it be used to determine the air change rate in the house as a whole?

D. Grimsrud (U.S.A.) — *I do not know about the tests but the device has been made available commercially.*

Paper 8 : 'Ventilation and energy consumption: practical experience of problems related to ventilation in single family houses' presented by Christer Harrysson (Sweden)

P.F. Collet (Denmark) — We have made some measurements to identify where fresh air comes into a house with exhaust ventilation. The results show that it is easy to manipulate the ventilation openings so that the fresh air comes in where you want it.

Session 3

Tuesday afternoon - 21st September 1982

Chairman: David Harrje (U.S.A.)

Additional Paper B	'Natural ventilation in UK dwellings and the possibilities for design' presented by David Etheridge (U.K.)
G. Brundrett (U.K.)	The advocates of mechanical ventilation argue that such ventilation controls both direction and quantity of ventilation. The same air may fulfil two duties - picking up body odours from the living room and then removing moisture from the kitchen before extraction. Do you believe that this "directional" aspect is important?
D. Etheridge (U.K.)	*Yes, certainly. This feature is part of the ventilation efficiency term in the definition of "energy efficiency" given in the paper. It is a feature of simple extract fans, as well as whole house systems.*
B.E. Smith (U.K.)	I would be interested to hear your comments on the maxima in the curves of ventilation rate as a function of wind-speed (for certain rooms) shown in Figure 4.
D. Etheridge (U.K.)	*The figure illustrates that, although whole house ventilation rate may be independent of wind conditions, i.e. buoyancy dominant, this need not necessarily be the case for room rates. These will be much more dependent on wind speed and direction. For some rooms, an increase in surface pressures due to an increase in wind speed will oppose the internal pressures due to buoyancy. For these rooms, the ventilation rates will decrease with increase of wind speed For other rooms, wind and buoyancy will act in unison to cause an increase in ventilation rate.* *This single explanation takes no account of the effect of changes in (a) wind direction or (b) the position of the neutral plane inside the dwelling. Theoretical calculations with our mathematical model indicate that these can lead to maxima and minima, as apparent in the figure.*
Paper 9 :	'Experiments with a passive ventilation system' presented by Ken Johnson and Geoff Pitts (U.K.)
R. Gale (U.K.)	I can offer you a method of measuring the flow in the duct. One injects tracer gas at a known rate into the bottom of the duct and measures its concentration at the top. This method can be used to monitor continuously the flow rates. A tracer gas unaffected by moisture is required.
W.F. de Gids (Holland)	Can you give the pressure-flow characteristic of the self regulating grilles?

K. Johnson & G. Pitts (U.K.)

Grilles have a plastic sac which is supposed to expand as air flow around it increases. The presence of the sac itself obstructed flow and flows were insufficient to actuate the mechanism, so no knowledge was built up of their characteristics. They were totally unsuitable for this particular application.

T. Hestad (Norway)

Scandinavian experience with supply air inlets in houses with natural ventilation or extract fan systems is that normal supply openings in window frames always cause draught problems.

Supply openings sited behind radiators (electric or water) using a special design with a shut-off damper (Figure D2) I have proved to be successful both in practice (40 years of use in Sweden and Norway) and in laboratory tests carried out in the National Swedish Institute for Building Research. As commented by Professor Peterson, this design also increases the efficiency of water radiators by up to 30%.

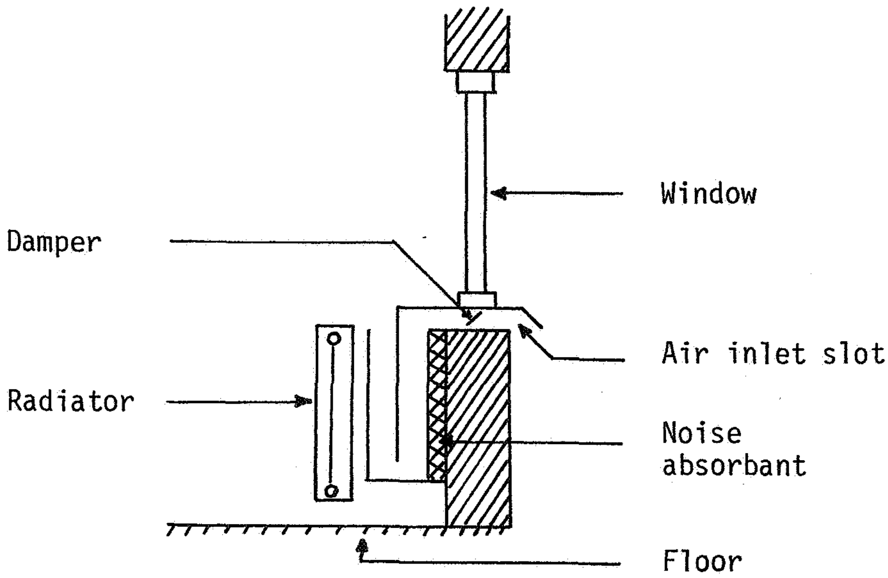


Figure D2

Paper 12:

'Effect of a gas furnace chimney on the air leakage characteristics of a two-storey detached house' presented by Chia-yu Shaw (Canada)

G. Brundrett (U.K.)

In your presentation you show the great care that goes into maintaining an intact vapour barrier at the wall. However, from your data, it would appear that much of the ventilation leaves the house through the loft. Why does the vapour barrier care not apply to the bedroom ceiling?

C-y Shaw (Canada)

Yes, there is vapour barrier in the ceiling. The vapour barrier was applied with the same care as that in the wall.

C. Allen (U.K.)

You expressed some surprise at the degree of similarity in the infiltration rates whether or not the gas furnace was operating. Surely the flow would be dominated by the highest resistance in the flow path, i.e. the walls.

C-y Shaw (Canada)

We were surprised since the walls were leakier than we expected.

Session 4

Wednesday morning - 22nd September 1982

Chairman: Peter Hartmann (Switzerland)

Paper 13: 'Definition of ventilation efficiency and the efficiency of mechanical ventilation systems' presented by Mats Sandberg (Sweden)

(Discussion not reported)

Paper 14: 'Field trials of ventilation efficiency in buildings equipped with mechanical ventilation systems' presented by Carl-Axel Boman (Sweden)

D. Grimsrud (U.S.A.) How dependent is the mean efficiency you measure (such as in diagram 1 on page 14.5) on your choice of measurement locations?

C-A Boman (Sweden) *I cannot give you an answer about the range of variation with position of the measurement points, but I would like to add this to our future investigations.*

F. Peterson (Sweden) This paper and particularly Figure 5 are rather interesting. I would like to add to it. By having the supply air and exhaust air openings in the centre of the ceiling, it is possible to improve the efficiency a great deal.

C-A Boman (Sweden) *We have not examined this case but I would like to add it to our future tests.*

F. Peterson (Sweden) Have you linked the influence of sunshine and thereby heated floor and window to the efficiency of a ventilation system? Some of our work has indicated this effect to be rather large and, in some cases, destroys the original flow pattern.

C-A Boman (Sweden) *I would like to add this type of investigation to our field trials.*

Paper 15: 'The efficiency of ventilation in a detached house' presented by Rodney Gale (U.K.)

D. Harrje (U.S.A.) Please explain further the spread of pollutant flow in the test house as indicated in Table 2. What is the heating system and how do the pollutants move from floor-to-floor and room-to-room?

R. Gale (U.K.) *The movement into and out of rooms on a particular floor is by the normal exchange process which is facilitated by the doors being open. The movement between floors is mostly via the stairway. Warm air near the ceiling flows upwards* *and spreads out on the first floor. The return path is down the inside of the outside walls adjacent to the stairs to the ground floor level, so completing the cycle.*

M. Liddament (U.K.) — Under "natural" ventilation conditions, would you consider the ventilation efficiency and ventilation rate you measured adequate for building occupancy?

R. Gale (U.K.) — *The figure I showed, which is Table 1 of our paper, refers to a somewhat artificial case of summer ventilation with all windows closed. The house is rather tight, 7 air changes per hour at 50 Pa, and there were no motive forces for natural ventilation. The efficiency of ventilation was adequate, being close to 100% in all rooms. I do not think that occupants would have used the house as we did. With the mechanical extract system operating (the results are also shown in Table 1) the efficiency and ventilation rate would both be considered adequate for normal occupancy.*

Paper 17: 'Energy conservation by regulation of the central mechanical ventilation system in high rise buildings: realistic or not?' presented by Willem de Gids (Holland)

R. Gale (U.K.) — You showed a slide which indicated that the savings made by reducing the fan speed could be cancelled out by occupants opening two windows. Did you examine the effects of opening windows with the fan at full speed?

W. de Gids (Holland) — *We did (see Figure 9). The flow through open windows is superimposed on the flows through the adventitious openings calculated using the pressures due to wind, temperature and fans.*

Session 5

Wednesday afternoon - 22nd September 1982

Chairman: Rodney Gale (U.K.)

Additional Paper D — 'The impact of ventilation and airtightness on energy consumption' presented by Arne Lögdberg (Sweden)

M. Liddament (U.K.) — What is the leakage of the slot vents?

A. Lögdberg (Sweden) — *The slot vents have an open area of up to 200 cm^2.*

Paper 18: 'User experience of mechanical ventilation in houses' presented by Don Dickson (U.K.)

D. Etheridge (U.K.) — What is the pay-back period for the system and on what natural ventilation rate is this based?

D. Dickson (U.K.) — *Each air change per hour costs 4000 kwh/year, i.e. about £100. This mechanical system provided 0.5 ach/h ventilation with 60% heat recovery plus 0.3 ach/h natural leakage and therefore, a ventilation heat loss of (0.4x2000) + (1200) = 2000 kwh/year or £50. For a system cost of £1,000, the payback is therefore 20 years compared to 1 ac/h natural ventilation but only 10 years compared to 1.5 ac/h.*

However, mechanical ventilation is installed not only to save money but to control the spread of contaminants, especially moisture, in a way which is difficult to achieve in any other way.

Session 6

Thursday morning - 23rd September 1982

Chairman: Lars Sundbom (Sweden)

Paper 20: 'The role of mathematical modelling in the design of energy efficient ventilation systems' presented by Martin Liddament (U.K.)

D. Etheridge (U.K.)
In section 4.2, are you saying that the neutral plane needs to be specified? This is not correct; it can be calculated. Our model has been doing this for several years.

M. Liddament (U.K.)
In many applications the neutral plane need not be specified. Instead, the stack pressure may be expressed relative to the lowest opening. The neutral plane may be determined by calculation, but it is not normally possible to measure the location of this plane directly.

D. Etheridge (U.K.)
Of the models you have looked at, how many use the power law? I believe it should not be used and that a quadratic equation is preferable. I hope to publish a short paper on this soon; it shows that there can be large and systematic differences between the two equations. Since there is more sound theoretical backing for the quadratic equation, it is probable that the use of the power law will systematically tend to over-estimate ventilation rates.

M. Liddament (U.K.)
The Air Infiltration Centre has made a study of fourteen models of which only the British Gas multi-cell model does not use the power law. It is hoped that the Centre's model validation programme will go some way towards indicating any problems resulting from the use of various assumptions in models.

Additional Paper C: 'Ventilation heat loss in a detached one-family house' presented by Thomas Lindquist (Sweden)

D. Harrje (U.S.A.)
Is the cavity behind the wood batten wall open to the outside environment at the bottom and top to remove moisture? The question then is how do those cavity pressures compare to the outside envelope pressures?

T. Lindquist (Sweden)
Yes, there is a space between the overlapping wood battens. There is also leakage between the overlapping wood battens themselves. A pressure gradient along the facade will thus cause air movements within the cavity. The flow resistances in the openings (in the wall) are, however, rather large in comparison with the flow resistance in the cavity. The resulting effect will be a moderated pressure gradient in the cavity which means that local high wind pressures will be smoothed out. Possibly the back-front pressure differences will be reduced by cavity flow round the house corner.

THE AIR INFILTRATION CENTRE was inaugurated through the International Energy Agency and is funded by ten of the member countries:

Canada, Denmark, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States of America.

The Air Infiltration Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

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