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Paper 31

The influence of different ventilation devices on the occupants behaviour in dwelling

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Abstract

On basis of several case studies into the ventilation behaviour in dwellings in the Netherlands, it is possible to answer the question whether the type of ventilation device influences the behaviour of the occupants during mild winter periods (5°C).
The dwellings are discerned in three types:

- those with natural ventilation through passive stacks only;
- those with mechanical exhaust ventilation provisions;
- those with balanced mechanical ventilation provisions.

By means of questionaires in each of these dwellings characteristics of the households and the ventilation behaviour has been assessed.
Consequences with respect to the air change rates will be discussed too.

The mean conclusions are that:

- the ventilation by behaviour is related to the type of ventilation device installed in the dwellings;
- there seems to be a 'subjectively preferred' amount of total ventilation from mechanical devices and behaviour taken together;
- in naturally ventilated dwellings and controlled for non occupancy a risk group of 20% is estimated: occupants who tend to ventilate too little: controlled for smoking this is 10%;
- the type of windows or grilles available determine the ventilation more by behaviour than the occupancy of the dwellings in time and number.

Introduction

In the Netherlands much work has been done to study the inhabitant's behaviour with respect to ventilation in occupied dwellings and apartments.
Objectives of these studies are to get insight into the behaviour to calculate air flows and loss of heating energy, to estimate the consequencies for the indoor air quality, to know the circumstances during indoor climate and indoor air measurements and to advise the occupants as well as the manufacturers of the ventilation provision and building architects.
Results of these studies have already been published in (1, 2, 3, 4, 5).

Due to the increased air tightness of the dwellings, the planning of 'open kitchens' and windowless bathrooms and toilets and the exposition of high outdoor noise levels, in nearly all newly built or renovated Dutch dwellings, mechanical exhaust ventilation provisions have been installed to attain the minimal desired ventilation

demand for dwellings of 150 m^3/hs (42 dm^3/s) or 25 m^3/h (7 dm^3/s) per person in the living-room.
Apart from this more and more dwellings are provided with balanced mechanical ventilation provisions in order to save of heating energy, the use of warm air heating systems and to prevent or to decrease problems with moisture and mould.

The question can be posed whether the type of ventilation devices influences the ventilation by behaviour by the occupants of dwellings. On .basis of the already available data and an additional field study this has been investigated with respect to a mild **winter situation** with outdoor temperatures of about 5°C and a wind speed lower than 5 m/s.
The resulting air change rates and the possible consequences with respect to subjective experienced health problems will also be discussed.
Three types of ventilation devices in single-family and apartment dwellings are discerned:

- those with natural ventilation through passive stacks only (N=137);
- those with continuously operating mechanical exhaust ventilation provisions (N=133);
- those with balanced mechanical ventilation provisions (N=145).

Also characteristics of the type of households have been introduced as factors: the number of involved persons and hours present in the home.

The use of ventilation provisions by behaviour is twofold: inhabitants 'ventilate' and 'air'. These two types of inhabitants behaviour will be distinguished in this paper.
To **ventilate** by behaviour is defined as providing continuously a certain rate of fresh indoor air by using ventilation grilles and vent lights or by casement windows or pivot windows set ajar. To keep an internal room door opened can also be viewed as a way to ventilate.
It has been calculated (and measured) that at a wind speed lower than 5 m/s and an indoor-outdoor temperature difference of 15°C the ventilation air flow will

vary between 2-10 m^3/h or .5-3 dm^3/s (grilles) to 50 m^3/h or 14 dm^3/s (totally opened vent light) approximately (6)*).

An open internal door (with an open surface of 1.5 m^2) can generate air flows even up to 600 m^3/h if the temperature difference between the hall and the room is 4°C.

Airing is the opening of pivot or casement windows,more than ajar during a certain period. During a mild winter period (+5°C) and a low wind speed this results in air flows varying between 35 m^3/h (or 10 dm^3/s) to 400 m^3/h (110 dm^3/s) depending on the width of opening of the windows.

Figure 1 illustrates the different windows or ventilation provision mainly applied in Dutch dwellings, as well as the indications of the air flows through these provisions during the given mild winter period.

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* The mathematical formula of the air flow stream (in dm3/s) is as follows:

$$q_v = \frac{a}{2} \times \sqrt{\frac{1}{100} + 0.001 \times V_w^2 + 0.0035\, H + \Delta t}$$

Where a = measured open window surface (in m^2)

$\frac{1}{100}$ = air turbulance

V_w = meteorologic wind speed (m/s)

H = height of open window

Δt = mean temp. difference inside/outside (°C)

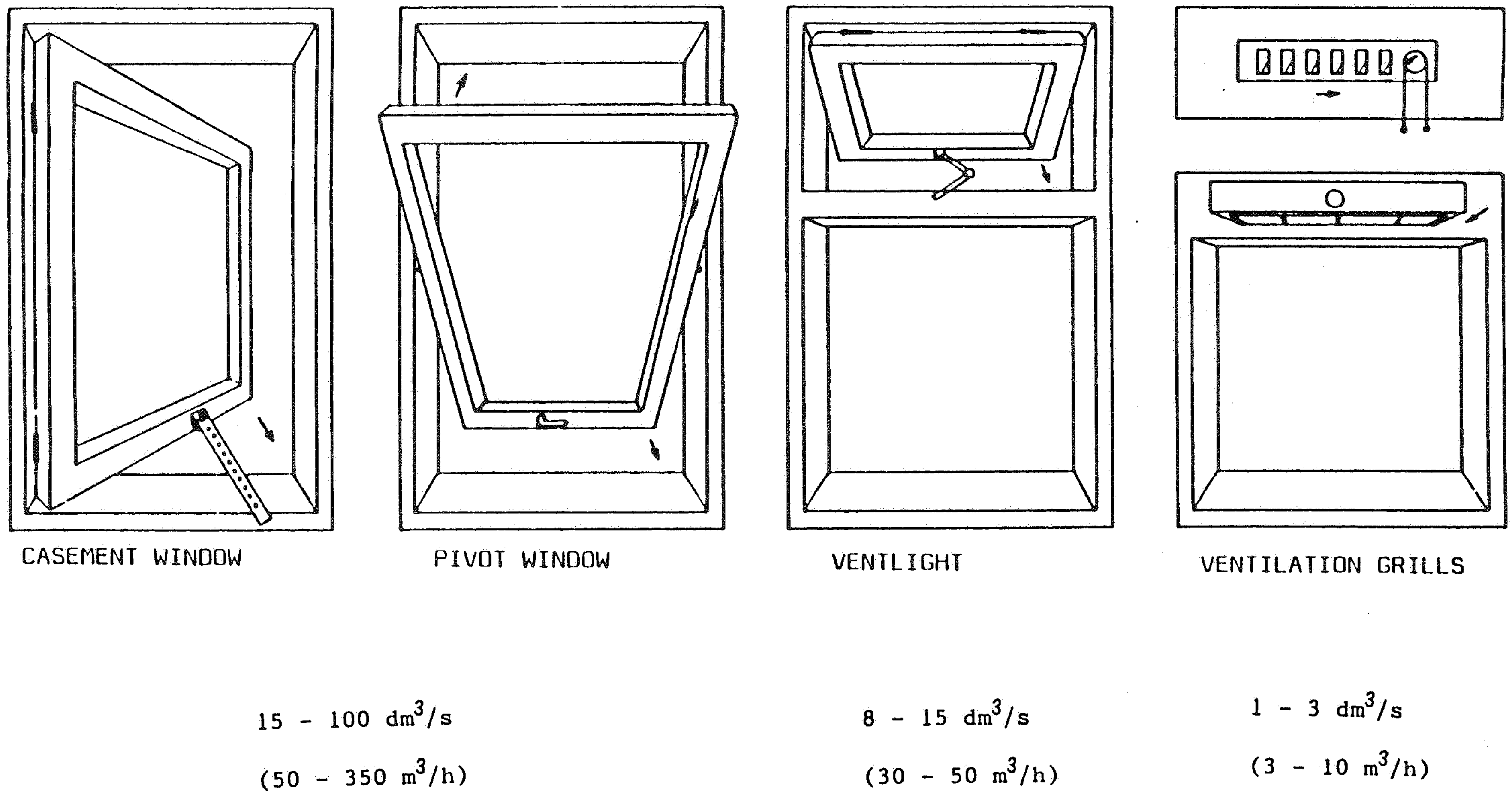

Figure 1 Types of windows or ventilation provisions applied in the different locations of studies

Results

In the framework of this study, per type of ventilation provision the length of time during which the windows and grilles were opened to ventilate or to air has been assessed in three rooms: the living-room, the main bedroom and the kitchen.
If more provision are used per room at the same time (e.g. a grill and a window ajar) the provision which is opened longest has been used as yard-stick with the exceptions that if two or more provisions in the same room are opened 0-1 hour or at least 8 hours opened, this has been recoded to one provision which is opened 1-4 hours and 24 hours respectively.
There was also consideration given to the combined situation of airing and ventilation.
The use of the **extractor hood** as a special device above the cooking range has been excluded from the tables. From (7) it appeared that in 61% of the Dutch households this extractor hood is present. Their use is actually restricted to the cooking hours, because the ventilatior noise level is very high.

The tabels 1 to 4 and figures 2 and 3 show the main results discerned on basis of the type of ventilation devices.

hours open	living-room only nat.vent. %(n)	kitchen only nat.vent. %(n)	living/kitch. contin. mech.vent. %(n)	living/kitch. balanced vent. %(n)
0	44 (47)	9 (10)	15 (20)	60 (87)
0-1 (0,5)*	22 (23)	27 (29)	9 (12)	14 (21)
1-4 (2,5)	9 (10)	31 (33)	21 (28)	16 (23)
4-8 (6)	4 (4)	5 (5)	11 (15)	1 (2)
> 8 (12)	10 (11)	15 (16)	9 (12)	2 (3)
24 (24)	10 (11)	12 (13)	35 (46)	6 (9)
mean hours ventilation	4,3	6,0	10,6	2,3
mean hours open if ventilated	7,7	6,6	12,5	5,7
open inward doors (to hall/stair well)	12,9	19,6	7,9	2,7**
ventilator on high speed	-	1	2,7	1,7

* between brackets: hours used for calculation of means
** closed in 89% of the dwellings

Table 1. **Ventilation** by behaviour through windows or grilles in **living-room and kitchen.**

hours open	only nat.vent. %(n)	contin. mech.vent. %(n)	balanced vent. %(n)
0	13 (18)	16 (21)	26 (38)
0-1 (0,5)	4 (5)	5 (7)	8 (12)
1-4 (2,5)	3 (4)	9 (12)	6 (9)
4-8 (6)	4 (5)	8 (11)	2 (3)
> 8 (12)	18 (25)	21 (28)	19 (28)
24 (24)	58 (80)	41 (54)	38 (55)
mean hours ventilation	16,5	13,0	11,7
mean hours open if ventilated	19,0	15,5	15,9
open inward doors	8,2(N=52)*	12,4	14,8 (N=133)*

* not known from all studies

Table 2. **Ventilation** by behaviour through windows or grilles in the **main bedroom**

hours open	living-room only nat.vent. %(n)	kitchen only nat.vent. %(n)	living/kitch. contin. mech.vent. %(n)	living/kitch. balanced vent. %(n)
0	40 (42)	64 (68)	52 (69)	74 (108)
0-1 (0,5)	36 (38)	25 (27)	36 (48)	22 (32)
1-2 (1,5)	7 (7)	8 (9)	7 (9)	1 (2)
2-4 (3)	8 (9)	0 (0)	3 (4)	1 (1)
4-8 (6)	6 (6)	2 (2)	2 (2)	1 (1)
>8 (12)	4 (4)	0 (0)	1 (1)	1 (1)
mean hours airing	1,3	0,4	0,6	0,3
mean hours open if airing	2,2	1,0	1,1	1,1

Table 3. **Airing** through windows in **living-room and kitchen.**

hours open	only nat.vent. %(n)	contin. mech.vent. %(n)	balanced vent. %(n)
0	28 (39)	55 (73)	32 (46)
0-1 (0,5)	20 (28)	20 (26)	28 (40)
1-2 (1,5)	9 (13)	2 (2)	9 (13)
2-4 (3)	11 (15)	7 (9)	6 (9)
4-8 (6)	7 (10)	7 (9)	8 (12)
>8 (12)	23 (32)	11 (14)	17 (25)
mean hours airing	3,8	2,0	3,0
mean hours open if airing	5,3	4,4	4,4

Table 4. **Airing** through windows in the **main bedroom.**

Summarized the results in the tables can be formulated as follows:
With respect to what has been defined as **ventilation** it was found that in the dwellings with a continuously operating mechanical ventilation system the **living-open plan kitchen rooms** are ventilated longest, especially where grilles were installed in

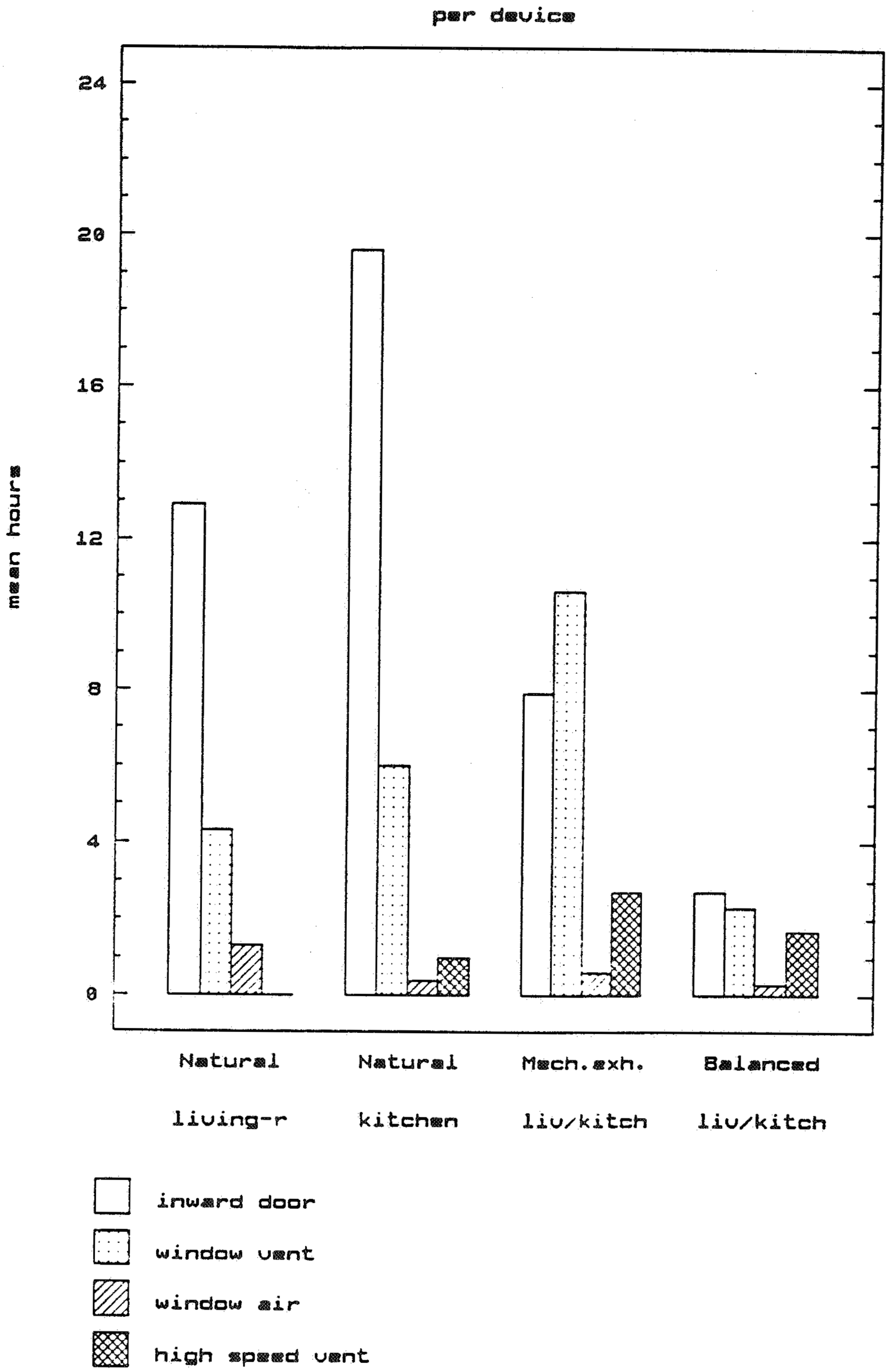

Figure 2 Use of provisions in living-room/kitchen

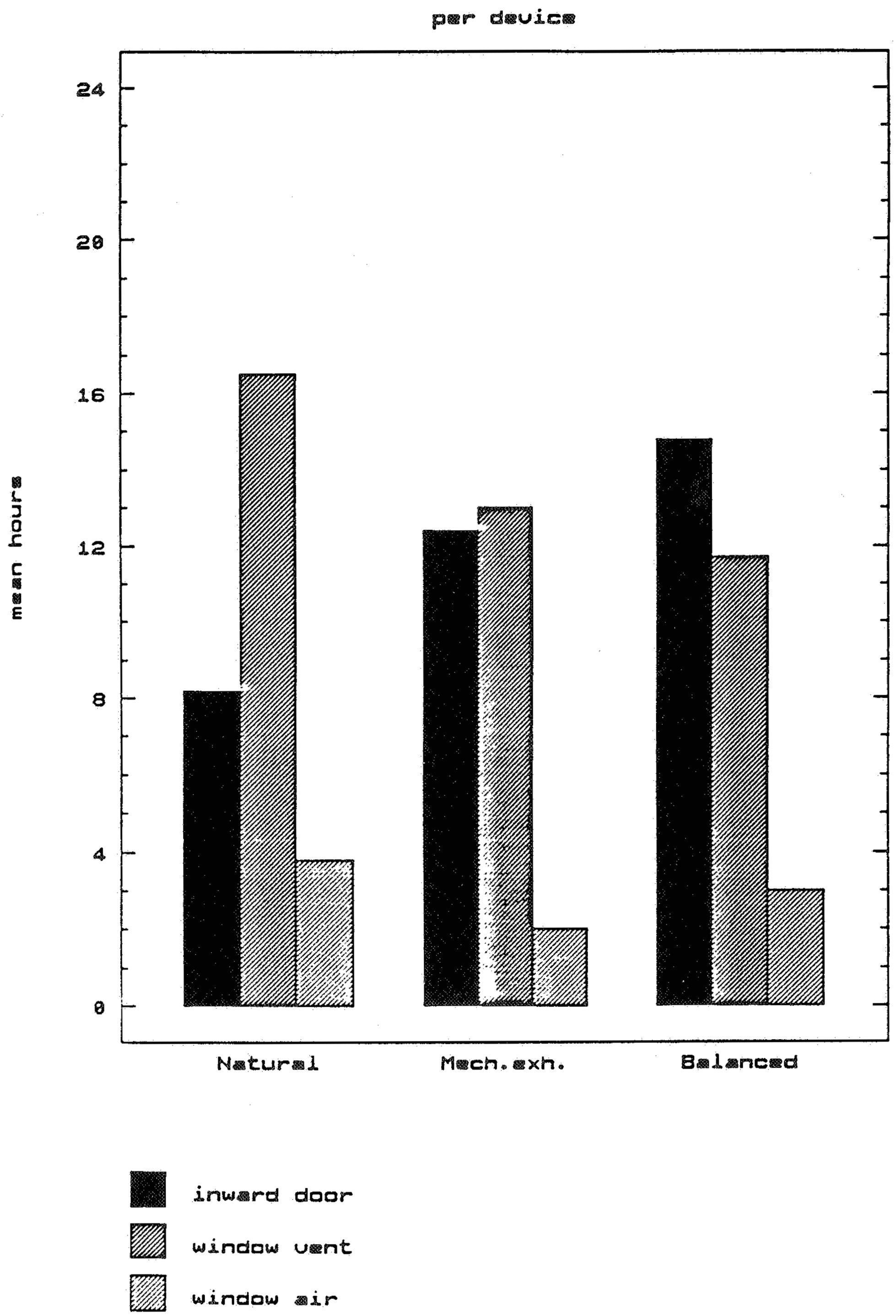

Figure 3 Use of provisions in main bedroom

the dwellings. If grilles are installed in these dwellings they are used by 85% of the households and if opened this is during 12.5 hours on the average.
In the dwellings with a balanced ventilation system, as wished and advised by the developers, the living/kitchen rooms are ventilated least through the window provisions (by 40%) and, if this is done, shortest: 5,7 hours on the average.
The inward doors to the living-rooms were predominantly kept closed too especially. This is in contract with the use of these doors in the only natural ventilated living-rooms, which are opened about five times longer.
The high speed of the ventilators are only used 1 to 2,7 hours per day on the average, mainly at cooking or bathing time. The noise annoyance was the main reason not to use it for a long time. From (8) it is known that an equivalent sound level of 30 dB(A) immitted from a ventilator into the living-room already gives rise to about 25% or sometimes annoyed occupants.
In dwellings (n=19) with a balanced mechanical ventilation system, provided with a Relative Humidity control at 60% RH, it appeared that during winter time this RH high is rarely reached.
In the **main bedrooms** the influence of the type of ventilation device appears to be less, although in the dwellings with a balanced system the use of windows to ventilate is lowest. Furthermore it can be seen that the use of the inward doors clearly negatively correlates with the use of the windows to ventilate.
With respect to what has been defined as **airing** it is found that in living-rooms with natural ventilation the windows are used more to air than those with mechanical ventilation provisions. This is also the case in the bedrooms.
In the dwellings with balanced mechanical ventilation systems the use of windows to air was mostly restricted in the living-rooms, as was the case with the ventilation by behaviour mentioned before. However this was not the case in the bedrooms, which might be explained by the fact that a number of occupants (17%) experienced the air from the system not as "hot fresh" **and** as "too dry".
Evaluating the results it was remarkable remarkably found that the total air flow created by the occupants behaviour appears to depend on the three discerned ventilation types but in such a way that the **total** amount of **air flows** created by dwelling characteristics (airtightness), ventilation systems and ventilation behaviour is more or less of a fairly **constant level**.
The same finding has already been shown in (1, 2, 3) with respect to the different types of windows in the living-room.
If the air flows shown in table 5 are assumed it is calculated that for the living-rooms and the main bedrooms this amount of 'subjectivity preferred' air exchange is in the range of 45-60 dm^3/s or 160-210 m^3/h each during a 24 hours day (see figure 4). Only in the living-room of the balanced ventilated dwellings the ventilation by behaviour was less; 35 dm^3/s or 126 m^3/h, but this was influenced by the

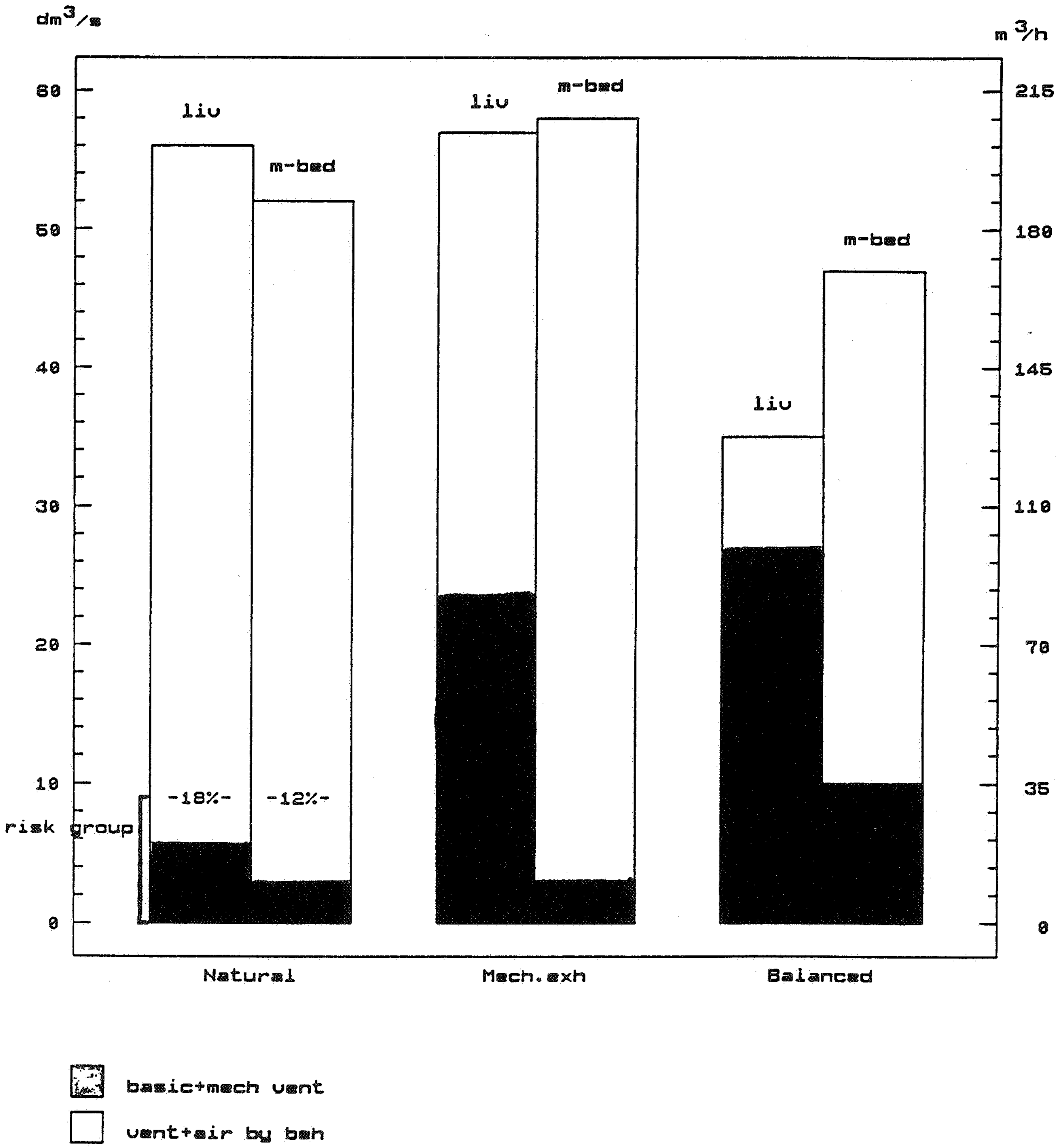

Figure 4 Calculated air flow per type of device

instruction to minimize this behaviour since this would disturb the balanced system.
This suggests that independent of the type of ventilation device there seems to be a certain constant total amount of air exchange which the occupants actively try to obtain by the use of windows or the other provisions in order to feel comfortable.

		m^3/h	dm^3/s
- window opened more than ajar		300	83
- ventlight or window		40	11
- grill opened		10	3
- inward door open and temp. diff.		300	83
- inward door open and few temp. diff.		150	42
- ventilator on low (standard) speed		60	17
- ventilator on high speed (living-room)		100	28
- balanced systeem	living-room	75	21
	bedroom	25	7
- leaks in walls of living-room		20	6
- leaks in walls of bedrooms		10	3

Table 5. Assumed air flows per source

Combined use

In practice the ventilation provisions to air or to ventilate, are used in combination with each other.
To get insight into the proportion of dwellings in which the ventilation by behaviour is low, those dwellings are selected where per day in the different rooms

- a window is opened more than ajar < 1 hour or
- a ventlight or window is opened ajar < 4 hours or
- a grill is opened < 8 hours or
- a ventilator is on high speed < 1 hour or
- an inward door is opened < 1 hour
  (if temperature differences or "fresh air flows" exist) or
- an inward door is opened < 4 hours (if temperature differences or "fresh air flows" are very low).

	nat.vent. %(n)	mech.vent. %(n)	balanced vent. % (n)
living-room	18 (19)	13 (1)*	-
kitchen (separate)	20 (21)	88 (7)*	-
living/open kitchen	19 (6)	7 (9)	60 (67)
main bedroom	12 (17)	13 (17)	5 (7)

* Small number of cases (N=8)

Table 6. Percentages low ventilating by behaviour

Especially in the natural ventilated dwellings these figures (controlled for non-occupancy of the dwellings during the daytime for more than 20 hours per week) give an indication of the population at risk: at first in about 20% of the living-rooms and kitchens the ventilation seems to be too restricted, e.g. in the order of less than 3 dm^3/s or 10 m^3/h on the average during a 24 hours day. In practice in the living-room of this group the air exchange rate might be about 5 dm^3/s higher due to building related air leakages and in the kitchen about 10 dm^3/s due to a ventilation duct and an extractor hood which is excluded here.
In 10(=40%) of these 25 natural ventilated living-rooms more than 5 cigarettes per day are smoked. So if smokers are excluded, the risk group is reduced to nearly 10%.
The results in table 6 also show that in the dwellings with a balanced mechanical ventilation system more than half of the occupants (as instructed) ventilate their living-room and open planned kitchen in a very restricted way.
However this did not appear to be the case in the main bedroom at night.

Health problems

In the case study in Den Bosch with balanced ventilated dwellings, experienced health complaints (extra fatigue, tickling nose and eyes, sneezing, sore throat, bad taste in mouth and, more especially where is smoked, headache and dry skin) as well as the feeling that the indoor air from the inflow valves is "not fresh" are mentioned as reasons for additional ventilation by behaviour (5).

A conclusion which should be stated here, is that in spite of the fact that mechanical ventilation devices are developed to provide a seemingly sufficient amount of air, based on a chosen hygienic standard of 7 dm^3/s per person or 42 dm^3/s per dwelling for instance, in practice this appeared to be unsufficient, since this air is not experienced as fresh enough, or is still to much polluted by indoor air pollutans like ETS, formaldehyde and dust. So additional use of windows and grills to ventilate or to air must be kept possible to allow occupants to react gradually (on a stepwise way) to get rid of their experienced problems.

Influencing factors

In general the finding in (3) is confirmed that the **number of persons** in a household **does not** influence the length of ventilation or airing by means of windows or grills in the kitchens and living-rooms (see Table 7). However a positive relation has been found between the use of the **high speed** of the ventilator (if this provision is present) and the number of occupants per dwelling. The high speed is used by about 25% of the 1-2 person households, 35% of the 3 person households and

50% of the 4 or more person households. In the main bedrooms (which are always used for sleeping) the use of the provisions to ventilate and to air is independent of the number of persons too, but as a matter of course in total the use of bedroom windows per dwelling will rise if more bedrooms are used for sleeping. On the average a window in a childrens bedroom is opened about half as long as in a parents bedroom.

CLIMATOLOGICAL FACTORS:

* less ventilation when:
  - the outdoor temperature is lower
  - windows are less oriented to the sun
  - windows are more oriented to the prevailing wind direction

HUMAN FACTORS:

* daily patterns in household activities
* less ventilation when:
  - the inside temperature is higher (as preferred)
  - the occupants are less energy conscious
  - the occupants prefer less fresh air
  - no respiratory diseases occur

ENVIRONMENTAL FACTORS

* less ventilation when:
  - condensation or mold growth are not perceived
  - the moisture production in the dwelling is lower
  - noise or odor annoyance has been experienced from outside

ARCHITECTURAL FACTORS:

* type of rooms
* type of ventilation provisions and heating systems
* less ventilation when:
  - the basic natural ventilation is higher through cracks
  - the volume of rooms is smaller
  - the occupants are conscious of an installed mechanical ventilation (which is not noisy)

Table 7 List of factors influencing airing and ventilation of dwellings by behaviour (from (3))

The hypothesis that **non occupancy** of the dwellings during the daytime of more than 20 hours per week influences the rate of **ventilation** by behaviour has not been confirmed in general. The type of ventilation provisions and the possibility

of burglary are the dominant factors here: where dwellings are provided with grills, especially in the bedrooms these grills opened even longer when no one is st home. Only in the living rooms of the dwellings with a balanced mechanical ventilation system has a significant different use of the provisions to ventilate been found in relation to the presence at home.
Also with respect to **airing** the relation with absence appeared weak in general. Difference in behaviour only exists in the living room, but not in de bedrooms: where dwellings are often unoccupied during daytime, less than one hour per day is aired in 95% of the dwellings and is never aired in 70% of the dwellings. In more or less continuous occupied dwellings these percentages are 80% and 50% respectively.

Conclusions:

Summarized, the data presented here lead to a number of conclusions:

- With respect to **ventilation by behaviour** a strong relation has been found with respect to the type of ventilation provisions installed in the dwellings and the use of windows or grilles in terms of hours of opening. With respect to **airing** this relation is weak, especially in the bedrooms.
- From calculations based on the occupants' use of windows and grilles to ventilate and air it appeared that, independent of the type of ventilation provisions and air tightness of the dwellings, there seems to to be a certain **constant total** amount of air exchange, induced by behaviour **and** by mechanical provisions together, which the majority of the occupants try to obtain in order to feel comfortable:
  For the living-rooms this average amount of 'subjectively preferred' air exchange is about 175 m^3/h or 50 dm^3/s.
- However in about 20% of the **only natural by ventilated** dwellings and controled by non-occupancy the ventilation by behaviour appeared to be restricted to about 3 dm^3/s on the average during a 24 hours day in the living-rooms and kitchen. This flow can be increased by 5 dm^3/s due to air leakages in the living-room and with about 10 dm^3/s in the kitchen due to a ventilation duct or extractor hood, but even in those cases and, in view of the indoor air quality, this exchange rate is too low in most cases, especially in the living-room where people smoke, which is the case in 40% of them. The non smoking risk group is nearly 10%.
- In dwellings with a balanced mechanical ventilation system which in principle garantees an air flow of 42 dm^3/s (or 150 m^3/h) through the dwelling as a whole, a ventilation amount which in the Dutch standard is viewed as suffi-

cient, health and comfort problems can be expected due to indoor air sources, if additional use of windows and grills to ventilate by the occupants themselves is not possible.

- From the results in the case studies it appeared that the **number** of occupants **does not**, and **non occupancy** of the dwellings during daytime periods longer than 4 hours per day **only slightly** does influence the ventilation by behaviour. More determining than non occupancy is the type of window or grilles which are available: its user-friendliness, its possibility for stepwise regulation and its burglary preventing quality.

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Discussion
Paper 31

J. Van der Maas (LESO, Switzerland)

Can you say something more about the effect on the occupants behaviour of the instructions the occupants received (e.g. Balanced system).

W. de Gids (TNO, Netherlands)

The first few days after instruction people seemed to change their behaviour. After a few weeks they seemed to stick on their old behaviour again. Which means no change at all. Only a small group, namely the energy concious people had a slight change in the first few days.