VENTILATION BEHAVIOUR IN DUTCH APARTMENT DWELLINGS DURING SUMMER

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ABSTRACT

On the basis of the information from extensive technical measurements, interviews and diary forms, the way occupants open their windows in different rooms has been assessed. Calculations were made of weather and behaviour dependent air exchange rates and the quality of the indoor air and climate was evaluated. On the first view the results show that few indoor air problems are to be expected in summer. However, due to outdoor environmental circumstances, in a substantial number of dwellings the indoor air quality may be worse during summer than during winter.

INTRODUCTION

In 80 apartment dwellings in a block of flats in the city of Schiedam in the Netherlands, during november 1985 till april 1987 the state of in total 1280 windows being opened or closed was continuously registered into a computer by means of the use of sensors fixed to the window-frames.
In addition in january 1985 face-to-face interviews about the behaviour and opinion of the inhabitants has been obtained. Information has also been gained by means of diaries, containing subjective indoor air quality parameters, hourly information about presence at home and the way windows, inward doors and heating systems are used. No physical or chemical measurement of indoor air parameters were performed.
Results of the ventilation behaviour of the inhabitants during winter conditions have already been published (1, 2, 3).
However, in this paper mainly the ventilation behaviour and the experience of the indoor air and indoor climate during a 'Dutch summer' period is presented. More especially this concerns the period of 31 august to 7 september 1985, since during this periode diary forms were completed in 31 apartments, giving additional information on the width of window opening, which could not be monitored by the automatic sensor registration.
This makes it possible to estimate the exchange rates of air flowing into or from a room.

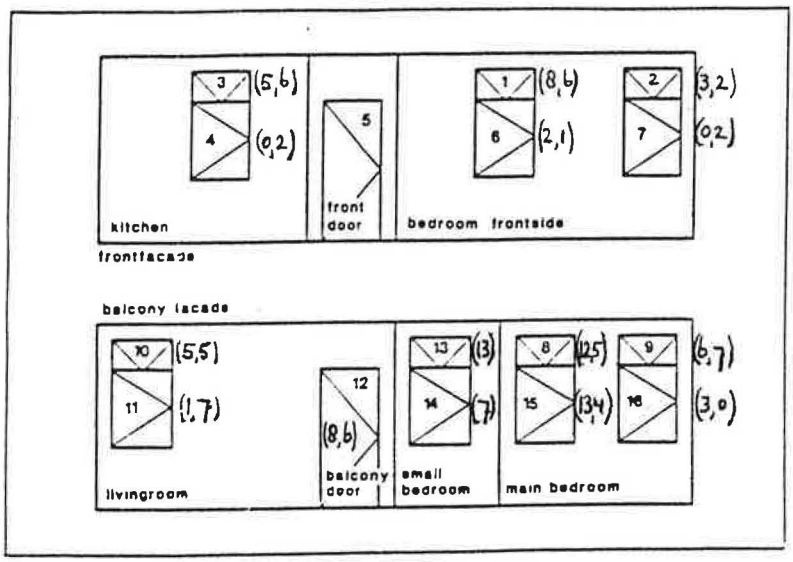
The dwelling

The flat-apartments are situated in a good 20-year-old 10 floors high building with 14 apartments on each floor. Each apartment consists of a living-room, three bedrooms, a kitchen and a central situated bathroom. The content of the living-room is about 78 m^3. The living-room, the main bedroom and a small bedroom are situated on the east oriented balcony side, the kitchen and another

bedroom are oriented to the open corridor facing to the west. Windows installed are casement windows, ventlights (top hung) and the balcony can be entered by a door from the living-room. The background (natural) air penetration surface (cracks) is about 130 cm^2 per apartment, which lead to a natural background ventilation flow of about 60 m^3 per hour.

Figure 1 shows the façades and the codification of the windows and ventlights. Between brackets the mean length of time per 24 hours the windows were opened during the diary period is indicated.
Furthermore it has to be remarked that a mechanical ventilation system is lacking.
In the kitchen and bathroom a combined duct has been installed for natural ventilation only. The calculated air flow through this duct is 60 m^3 per hour on average. The gas heated warm water geyser in the kitchen is not connected to an exhaust duct. The flat-apartments are not exposed to road traffic noise.
In 14% of the apartments problems are often or sometimes experienced with noise: from a schoolyard on the corridor side of the dwellings.
In 36% of the apartments odours from industrial sources sometimes cause nuisance problems.

Figure 1 Façades, codification and mean length of open ventlight, casement windows and balcony door (between brackets in hour per 24 h. day)



The occupants

Restricted tc the 31 apartments, where the diaries were filled in during the summer period, the following characteristics can be given to the households (which were not significantly different from those of the total 80 apartments).
The mean occupancy of the apartments is 2,7 persons (2 one-person, 12 two persons, 10 three persons, 7 four persons households).
In 5 (= 16%) of the households nobody was home during more than 28hoursper week. In 20 (= 65%) of the apartments more than five cigarettes are smoked per day.

The weather

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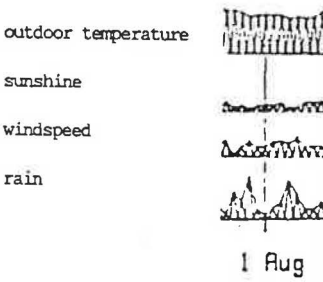

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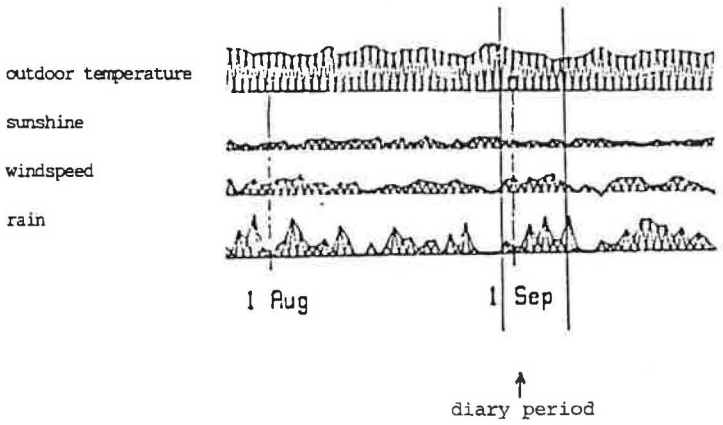
The weather

A general impression of the weather in august en september 1985 is given in figure 2. The more specific characteristics of the weather (measured near the balcony of an apartment) during the diary period of 31 august to 7 september (added with information of 30 august) are shown in figure 3. In summary the weather during that period can be characterized by mean 24-hour temperatures steadily falling from 19°C to 12°C (max 24°C, min 9°C), spells of rain on each day (especially on 3, 4, 5 and 6 september) and periods with a windspeed higher than 5 m/s (1, 3, 5 and 6 sept.). The four days before the diary period were charactarized by warm and very sunny weather with maximal temperatures up to 30°C. Consequently heat was accumulated in the concrete shell of the building, which will have influenced the experience of the indoor climate during the first two days of the dairy period.

Figure 2 Weather characteristics of august and september 1985



RESULTS

The experience of the indoor air and climate

Based on the questions in the diary forms information has been gathered on subjective experienced indoor air and climate problems. Table 1 shows (in percentages) the proportion of the apartments in which specific problems occurred.

With respect to the parameters "too cold" it is remarked that the central heating system in the building did not function during the summer period. The experience of "too cold" strongly correlates with the mean 24-hours outdoor temperature. In studies into the use of heating energy it is found that occupants start to heat the living-room when the mean outdoor temperature during daytime is lower than 16°C. The results here seem to support this behaviour. The experience of draught problems is especially related to the wind speed. So, by respondents "draught" seems to be defined as "windspeed" and not as "cold air flow from outside".

Figure 3 Outdoor climate circumstances on balcony side of the apartments

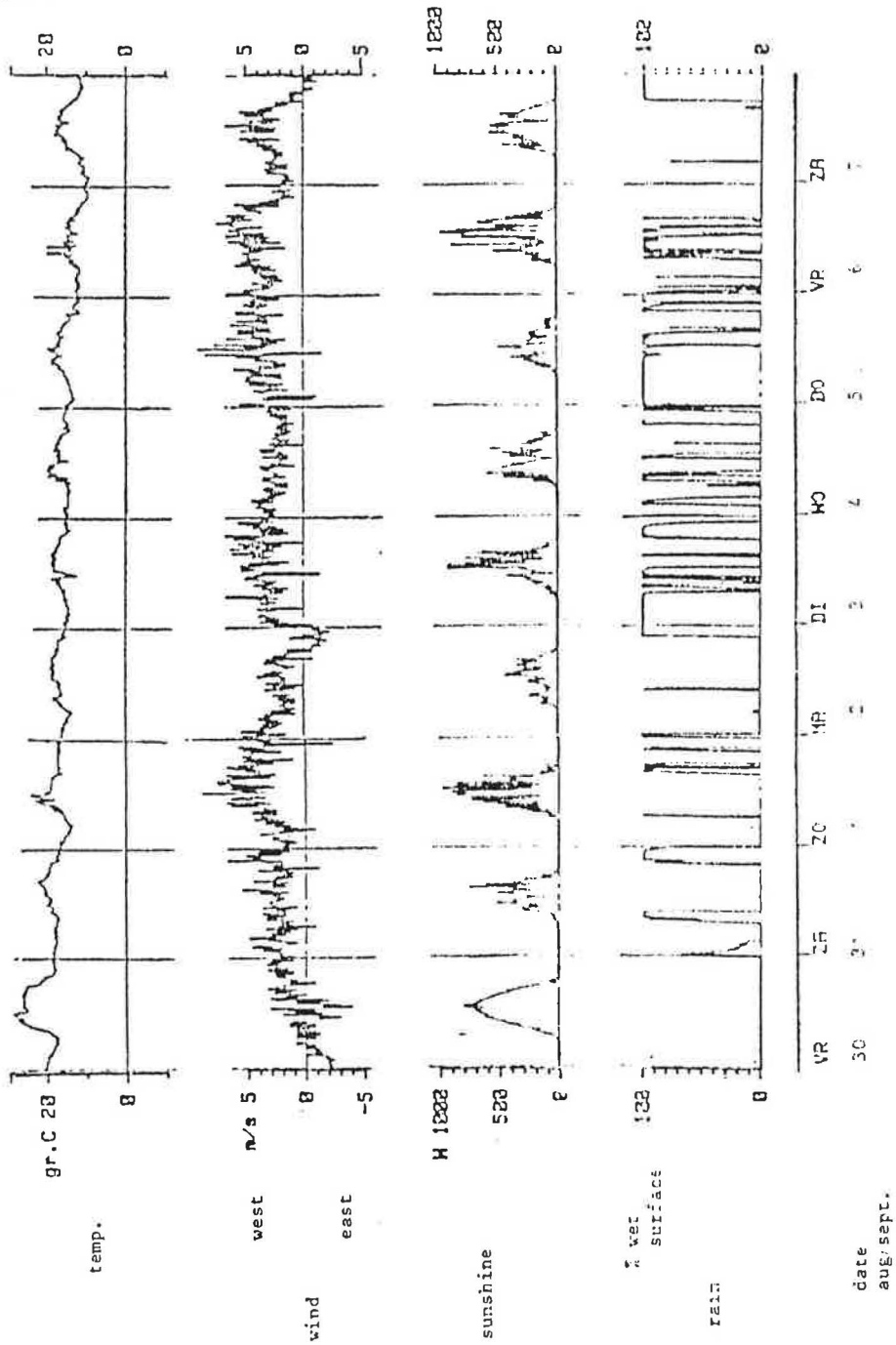


Table 1 Outdoor climate and indoo

date	outdoor climate* mean temp. °C	max temp. °C	wind speed m/s
30	22	30	3
31	19	23	4
1	18	24	6
2	17	19	3
3	17	18	6
4	17	19	3
5	15	19	7
6	13	19**	6
7	14	17	4

* Measured on balcony. The temp
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** Short peaks

The use of the windows

In figure 1 the mean lengt
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Table 1 Outdoor climate and indoor air and climate experiences

date	outdoor climate* mean temp. °C	max temp. °C	wind speed m/s	too warm %	too cold %	draught %	muggy %	smell %	damp %	too dry %
30	22	30	3	———		no information				
31	19	23	4	0	3	0	6	3	0	3
1	18	24	6	0	6	10	6	3	0	3
2	17	19	3	0	10	6	6	6	6	3
3	17	18	6	0	13	16	3	13	0	3
4	17	19	3	0	16	10	0	10	3	3
5	15	19	7	6	29	10	3	10	3	3
6	13	19**	6	0	42	19	0	6	0	3
7	14	17	4	0	32	6	0	3	0	0

* Measured on balcony. The temperatures are 2-4°C higher than in the free field situation

** Short peaks

The use of the windows

In figure 1 the mean length of time the windows were opened during the diary period is indicated between brackets. On average per apartment a window was opened 6,1 hours per 24-hours. (During a winter period with a mean outdoor temperature of + 3°C this was 2,7 hours and a winter period with - 2°C it was 1,7 hours).
In this paper the results with respect to the use of the windows will be restricted to those in the living-room, the main (parent's) bedroom and the kitchen (the windows/door with the codes 10, 11, 12, 8, 9, 15, 16, 3 and 4; see figure 1).

In figure 4 the use of these windows during the sensor-monitored period from november 1985 to april 1987 is illustrated. The use is operationized by calculating the percentages of the total number of the particular windows in the apartments (N=80) which are opened (y-axis) as a function of the outdoor temperature (z-axis) and the time of the day (x-axis).

The tables 2 and 3 show the mean length of time per 24-hours window(s) or balcony door in the living-room and the main bedroom were opened during the diary period in summer 1985, as well as the mean width of opening of the casement window (or balcony door), if opened. Herewith four rates of width of opening are distinguisted: 1 = ajar (2 cm); 2 = handwith (10 cm); 3 = fairly wide (30 cm); 4 = wide (70 cm). Also the mean length of use of the ventlight (code 10), if opened, is given.

Figure 4 The use of ventlights, windows and balcony doors in different rooms in percentages of the total number in the block of flats (Y) as a function of the outdoor temperature (Z) and the time of the day (X)

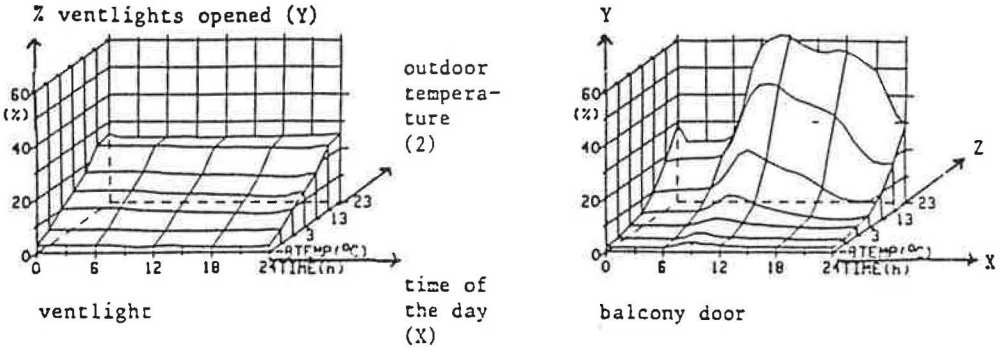

Table 2 Use of windows in the liv

date	outdoor climate* mean temp. °C	max temp. °C	wind/dir. speed m/s	
30	22	30	3	SE
31	19	23	4	SW
1	18	24	6	W
2	17	19	3	S
3	17	18	6	SW
4	17	19	3	NW
5	15	19	7	W
6	13	19	6	W
7	14	17	4	SW

* In same cases information was

Table 3 Use of windows in the mai

date	outdoor climate* mean temp. °C	max temp. °C	wind/dir. speed m/s	
30	22	30	3	SE
31	19	23	4	SW
1	18	24	6	W
2	17	19	3	S
3	17	18	6	SW
4	17	19	3	NW
5	15	19	7	W
6	13	19	6	W
7	14	17	4	SW

* In same cases informati

Estimated air volume flows

On theoretical level (
closed inward room door and
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Table 2 Use of windows in the living-room (mean length and width per day)

	outdoor climate*				casement window/door			ventlight	
	mean temp.	max temp.	wind/dir. speed		length in hours	width	opened	length in hours	opened
date	°C	°C	m/s		(N=31)	(N=21-27)*	% (n)		% (n)
30	22	30	3	SE	——— no information ———				
31	19	23	4	SW	14,2	3,6	94 (29)	22,0	29 (9)
1	18	24	6	W	13,0	3,2	94 (29)	21,6	29 (9)
2	17	19	3	S	11,1	3,5	97 (30)	24	23 (7)
3	17	18	6	SW	9,0	3,1	87 (27)	21,0	26 (8)
4	17	19	3	NW	10,4	3,1	97 (30)	24	23 (7)
5	15	19	7	W	8,1	2,8	94 (29)	22,0	23 (7)
6	13	19	6	W	7,5	2,7	97 (30)	19,9	23 (7)
7	14	17	4	SW	6,6	2,9	100 (31)	16,3	26 (8)

* In same cases information was missing

Table 3 Use of windows in the main bedroom (mean length and width per day)

	outdoor climate*				casement window(s)			ventlight(s)	
	mean temp.	max temp.	wind/dir. speed		length in hours	width	opened	length in hours	opened
date	°C	°C	m/s		(N=31)	(N=20-28)*	% (n)		% (n)
30	22	30	3	SE	——— no information ———				
31	19	23	4	SW	17,2	3,2	97 (30)	23,1	58 (18)
1	18	24	6	W	15,1	3,3	100 (31)	23,0	58 (18)
2	17	19	3	S	15,9	3,3	100 (31)	24	52 (16)
3	17	18	6	SW	13,7	3,4	90 (28)	23,0	55 (17)
4	17	19	3	NW	15,3	3,4	97 (30)	24	52 (16)
5	15	19	7	W	14,7	3,1	97 (30)	22,4	58 (18)
6	13	19	6	W	14,8	3,3	97 (30)	22,9	58 (18)
7	14	17	4	SW	14,7	3,2	87 (27)	19,8	65 (20)

* In same cases information was missing

Estimated air volume flows

On theoretical level (on basis of (4)) and at the assumptions of a closed inward room door and an indoor temperature of 21°C rough calculations have been made to estimate the air flows through the different types of provisions (ventlight, casement window and balcony door) in the living-room as a function of the width of opening and the weather conditions. With respect to the diary period, table 4 shows the results of the calculations per type of window provision and the width of opening

in mean air flows per day during one hour (based on the mean weather conditions per day).
These are provisional and must be viewed indicative only to a situation in a (living-)room on the balcony side (east-side) of the apartment with no or very limited air flow streams from or towards the rest of the apartment, since the inward door is assumed to be closed. In practice, however, this door is predominantly opened (19 hours on average), while other inward doors are opened too: the kitchen door (0,9 hour) and hall door (4,2 hours) on the west side; the door of the main bedroom (9,2 hours) and small bedroom (12,3 hours) on the east side.
So the real air exchange rate will be (much) higher. Unfortunately in this phase of research the modelling and calculations with respect to this real situation are not ready yet.

Table 4 Mean air flow per day during one hour (in m^3 per hour) per type of provision

type of provision	width (cm)	mean air flow in m^3 per hour per date								mean
		31	1	2	3	4	5	6	7	
ventlight	2	4	11	7	11	7	15	11	4	9
"	10	19	30	19	30	19	37	30	19	26
casement window	2	8	16	10	16	10	21	16	8	13
" "	10	37	51	36	51	36	60	51	37	45
" "	30	109	142	100	142	100	161	142	109	126
" "	70	255	325	230	325	230	364	325	254	288
balcony door	2	16	25	18	25	18	31	25	16	22
" "	10	77	99	73	99	73	111	99	77	88
" "	30	230	285	212	285	212	317	285	230	257
" "	70	535	658	490	658	490	728	658	535	594

The results show that the mean air flows per hour are lowest on 2 and 4 September and highest on 5 September. The provision specific flow values multiplied with the length of time the provisions were opened (see tables 2 and 3), divided by 24 hours, gives the theoretical calculated air exchange per hour per room during a 24-hours day under the conditions mentioned above.
If we only consider the living-room, the following mean air flows through the windows per day were calculated (in m^3 per hour); in succession (and in relation to the mean outdoor temperature dropping) from 31 august to 7 september: 246, 182, 165, 141, 138, 114, 76 and 69 m^3 per hour. So, during thediary period the lowest air exchange was 69 m^3 per hour on average per day, which still seems to be fairly sufficient (during the winter period this was 26 m^3 per hour (3)). Nevertheless in 11 (= 35%) living-rooms the air flow through the windows in this room appear to be low, i.e. less than 25 m^3 per hour. However in all these cases the inward door was opened continuously or during a long time opened. Together with the flows from the windows in the other rooms, especially those on the opposite side of the apartment, and the basic continuous natural flow through cracks (60 m^3 per hour per apartment), this can generate extra flows in the living-room in the range of 300 m^3 per hour.

Influencing factors

A number of factors
the use of windows during
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Summarized these are:
- The presence of the
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- The daily household a
- The outdoor climate:
- The indoor climate: d
- The quality of the o
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In more into detail:
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Influencing factors

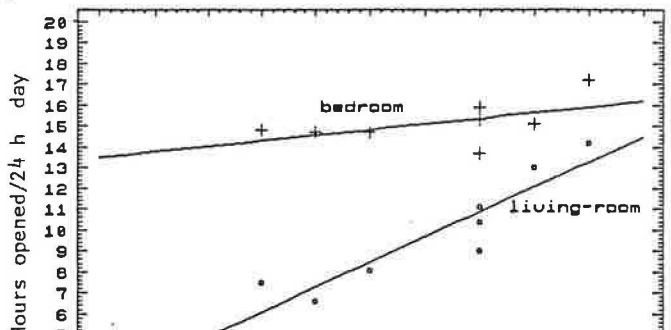
A number of factors can be distinguisted which appear to influence the use of windows during summer. These are partly different from factors playing a role in winter (1), because in summer occupants tend to maximize the ventilation rate, while in winter they tend to minimize it. Summarized these are:

- The presence of the occupants: on the corridor side of the apartments the windows or ventlights were opened maximal half an hour on average and on the balcony side maximal 1,4 hour when nobody was home. Fear for burglary as a matter of course plays a role here, but also for escaping of dogs and cats.
- The daily household and lifestyle patterns.
- The outdoor climate: temperature, windspeed, winddirection.
- The indoor climate: draught.
- The quality of the outdoor environment: air pollution (odour) and noise.

In more into detail:
With respect to the living-room and the bedroom(s) the general relation (shown in figure 4) between the percentages of opened windows and the mean outdoor temperatures, varying from -8°C to 23°C, will be clear. Furthermore can be seen that (with exception of the balcony door, code 12) the daily pattern to open windows (shown by the x-axis) is independent of the outdoor temperature. It is strongly related to housekeeping- and lifestyle-routines.
The windows in the kitchen (codes 3 and 4) appear to be opened relatively independent of the outdoor temperature. This use is closely connected with the daily cooking and washing patterns, as well as with the prevailing wind direction, causing draught or enabling the dwelling to cool off.
Specifically, restricted to the diary period during summer, with respect to the provisions in the living-room if was found what could be expected: the lower the mean outdoor temperature and the higher the wind speed the shorter and less wide the casement window or door were opened. Moreover, in living-rooms during the diary period experienced as "too cold" (see table 1), the casement window or balcony door were opened 3,8 hours per day shorter on average.
With respect to the ventlight in the living-room (code 10) it appeared that their use was very stable: they were nearly continuously opened on the same (seven) apartments and the mean length of time was more influenced by the behaviour in the two additional apartments than by the weather.
Concerning the use of the ventlights in the main bedroom the same conclusion can be drawn as to its use in the living-room. In 16 apartments the use of the ventlights was very stable: always opened. However, in contrast with the use of the situation in the living-room, the use of the casement window(s) in the bedrooms appeared not to be related to the outdoor climate conditions. Reasons for this are that bedrooms are mostly not occupied during daytime and that most occupants usually prefer "cool and fresh" bedrooms with maximal temperatures of 16°C.
A significant negative correlation ($p \leq .05$) was found between the use of the windows in the main bedroom and the living-room during winter (1). So the bedrooms seem to be used as a sluice to ventilate the whole apartment. Probably this is also the case during summer.

Figure 5 illustrates the relations between mean outdoor temperatures (in C°) and the length of opening of the casement windows (or balcony door) in the different rooms.
In the living-room the relation is significant (p=.001) and strong (r=.92)). The equation of the regression line is y=1.2x-9.47. It is absent in the bedroom.

Figure 5 Use of casement windows and/or balcony door in living-room and main bedroom



As contrasted with the use of windows during the winter periods (smokers ventilate twice longer on average), in summer smoking behaviour did not influence the length of time the windows are opened. While during the winter periods, in spite of the longer ventilation time, indoor air pollution due to tobacco smoke still caused problems in 24% of the living-rooms (a percentage which agrees with the mean situation found in different types of newly built dwellings in the Netherlands (3)), it is expected that these problems are less during the summer, since the air flows through the window(s) and balcony door are minimal higher than 300 m^3 per hour then.
(In (5) it is concluded that minimal 50 m^3/h air flow is required to prevent acute irritation from tobacco smoke, and minimal 120 m^3/h to avoid annoyance due to odour to passive smokers).
This expectation seems to be supported by the comfort evaluation with respect to indoor air aspects (see table 1), although this only reflects the situation over eight days. In the face to face interviews, held in winter, in 70% of the kitchens and 9% of the living-rooms the occupants said to experience problems with (cooking) smells from neighbours sometimes or often, in most cases due to "backflow" problems from the combined natural ventilations duct running along the kitchens and bathrooms. During the winter in the living-room of 31% of the apartments problems were experienced with condensation on windows, and in 40% with cold radiation or draught (3).
In general (so not restricted to this case study in question) the air exchange rate mentioned earlier seems to be sufficient to avoid problems with other indoor air pollutants like moisture, radon, combustion products, particulates, organic solvents and other organic components, probably with the exception of formaldehyde in particle board (6,7).
However problems can rise with respect to outdoor pollutants and agencies when it can freely flow through the windows into the dwellings like PAH (benzene), lead, CO, NO_x, SO_2, O_3, particulate matter and pollens,

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4. Phaff, J.C. et al. (19
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as well as noise and odour mostly orginating from motorized traffic, industrial, but also from agricultural and natural sources. These factors clearly influence the use of windows (8).
On national Dutch level a percentage of 19% of all dwellings are estimated to be regulary exposed to odours from traffic, industrial and agricultural sources (9). A relation between the concentration of outdoor odour and keeping or closing windows is proved in situations with a strong odour concentration, in half of the dwellings windows were kept closed (10).
The outdoor environmental factor noise also influences the use of the windows, although not in this case study in Schiedam, where outdoor noise is limited to noise from a schoolyard. On a national scale it is found that in 29% of all Dutch dwellings windows were regulary kept closed by reasons of noise (11). (In 38% of all Dutch dwellings people are more or less annoyed by traffic noise alone).

DISCUSSION

The results shown previously lead to the conclusion that the calculated and estimated air flow rates in the apartments of this case study in question are amply sufficient to prevent indoor air problems during summer, especially as the possibility and the way to regulate the width of opening of the windows is user-friendly.
The problems mainly are restricted to draught (or "indoor wind" flow), a non operating heating system when occupants want heating, and possibly less controllable, cooking smells from neighbours due to the lack of a central mechanical ventilation provision.
However the findings in this study are still representative of those situations where environmental pollution (often perceived by odours) and environmental noise influence the use of windows by the occupants. The fact that in a substantial number of dwellings (up to 30% in the Netherlands, and probably not much less in the other industrial and "civilized" countries) environmental problems are experienced, stresses the need to pay much attention to those specific situations. It is surely not out of the question that when windows are kept closed or opened shorter, in these dwellings the critical period for the indoor air quality is not the winter, but the summer period. This, since at the same length of time and width of opening of the windows, the air flow in winter is a factor 2 higher than in summer (at low wind speed).
In the Netherlands for dwellings or apartments a minimal air exchange rate of 150 m^3 per hour is desired. The Dutch ventilation standard is based on an air exchange rate of 25 m^3 per hour per person when a room is occupied.

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