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PAPER 20

INHABITANTS' BEHAVIOUR WITH REGARD TO VENTILATION; THE USE OF WINDOWS. FIRST HEATING SEASON.

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SYNOPSIS

A research is being carried out concernin g the use of windows and doors in an appartment building in Schiedam in the Netherlands.
The investigations consist of an inquiry and of continous measurements for a period of about two years on 1280 windows and doors of 80 dwellings. During the measurements there is only a distinction between the closed and not-closed positions of windows and outside doors, because simple switches are used.

The following conclusions can be drawn:

- the measurement technique is reliable even if the visibility is bad.
- there is a linnear relation between the weekly mean of the number of open windows and outside doors and the mean outside temperature.
- there is a characteristic day-night pattern for the use of doors, pivoting windows and flap windows for the living room, the bedrooms, the kitchen, galery side and balcony side.
- the most important motive for ventilation is the discharge of polluted indoor air.
- 25% of the windows that are open are set ajar, 75% are opened more wide.
- there is a good correspondence of the results of the inquiry and those of the measurements
- the windows and doors that are open during too many hours a day result in a mean estimated heatingloss of 4.5 GJ per heating season per dwelling.

1. INTRODUCTION

1.1 General

An investigation is being carried out By the TNO Division of Technology for Society concerning the use of windows and doors in an appartment building in Schiedam. Schiedam is situated at the west side of Rotterdam in the Netherlands.
The project that has been initiated by Switzerland within the frame of the International Energy Agency (IEA) program with the title : "Inhabitants Behaviour with Regard to Ventilation" (Annex VIII)

The situation on this moment is that Belgium, The Netherlands, Germany, Switzerland, and England participate in this research project. Belgium is the "Operating Agent".
Our measurements started on 26 November 1984 and will continue till the end of the heating season of 1985/1986.

1.2 Purpose

The purpose of the project is:

1. Determination of the inhabitants behaviour with respect to ventilation and its relations to the inner and outer climate conditions.
2. The estimation of the energy loss due to this behaviour.
3. The study of the motives of the behaviour.
4. The study of changes in the behaviour due to information and instruction to the inhabitants.

1.3 The building

In the middle of the building is a staicase and elevators. There are 14 dwellings per floor and 10 floors.
From the total of 140 dwellings 80 are taken on basis of willingness of the inhabitants, looking at the front facade 44 at the right of the staircase and 36 at the left (Figures 1 to 7).
Above every pivot window is a ventlight or flap window.

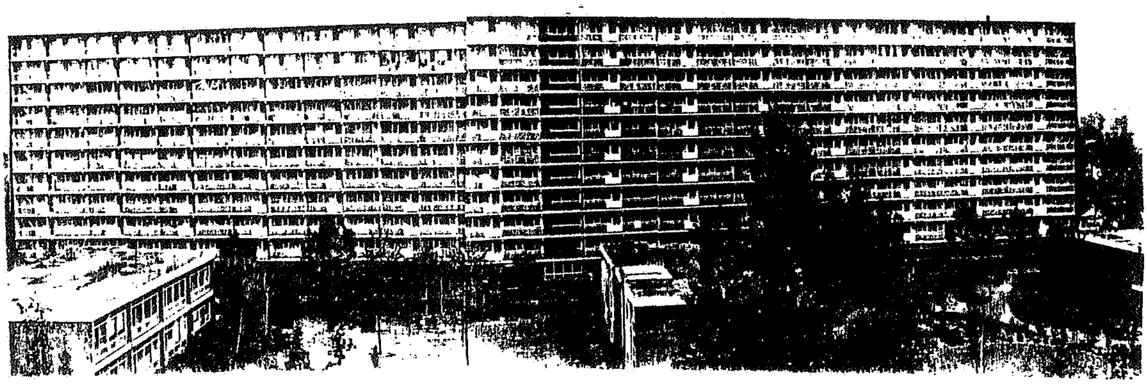


Figure 1 .Front facade as seen from the West.

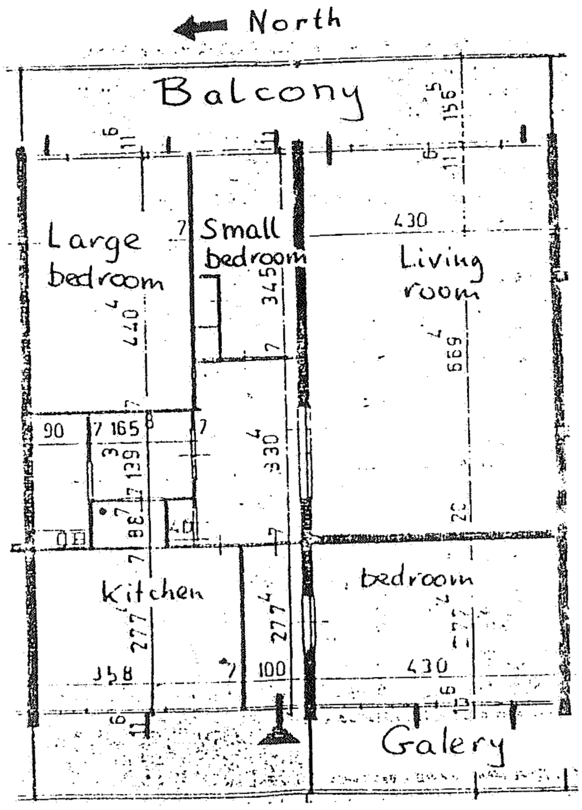


Figure 2 . Floorplan of one dwelling.

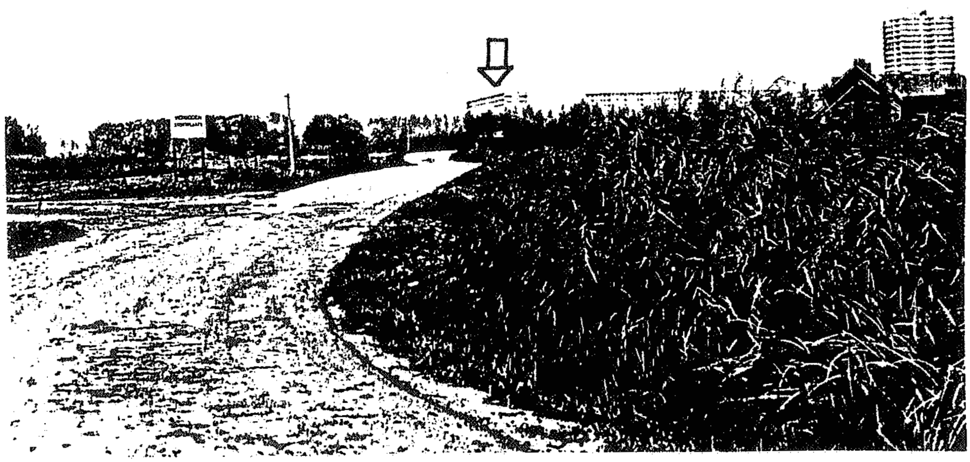


Figure 6 . The building as it can be viewed from the North-East.

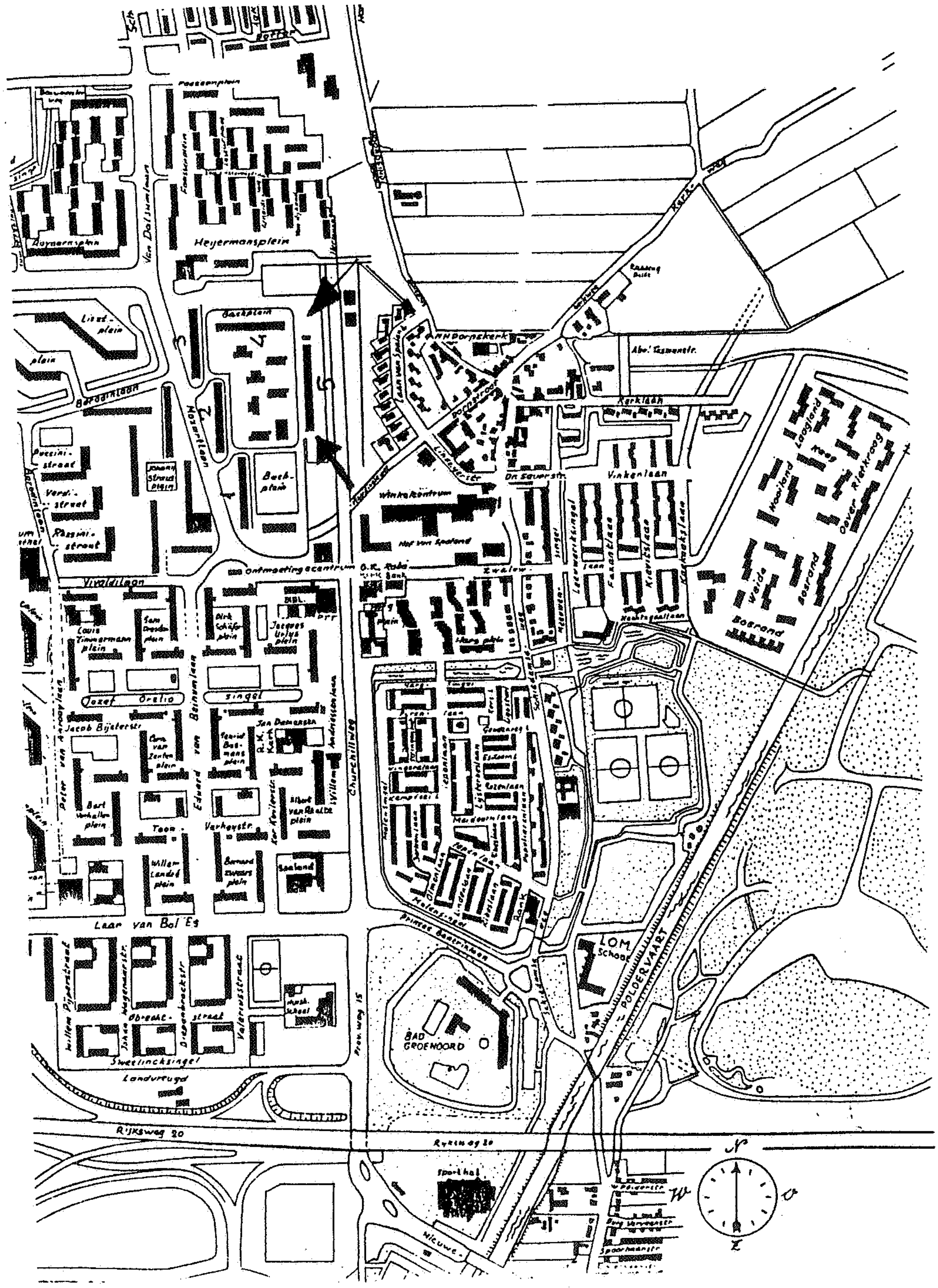


Figure 3 . Surroundings of the building.

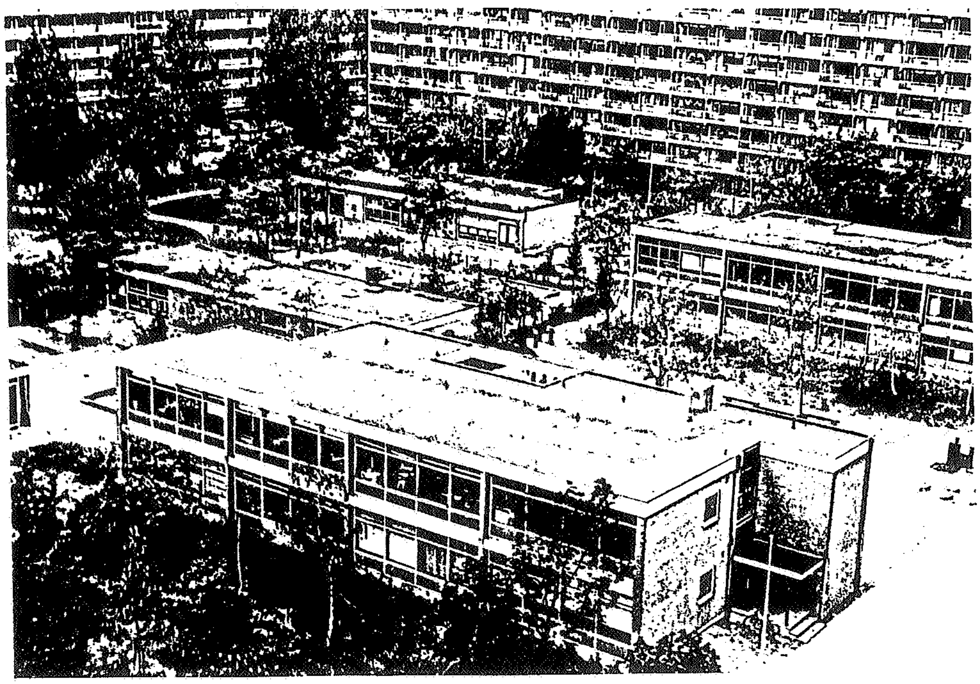


Figure 4 . Looking to the North-West from the building.

Figure 5 . Balcony facade of one appartment as seen from the East.

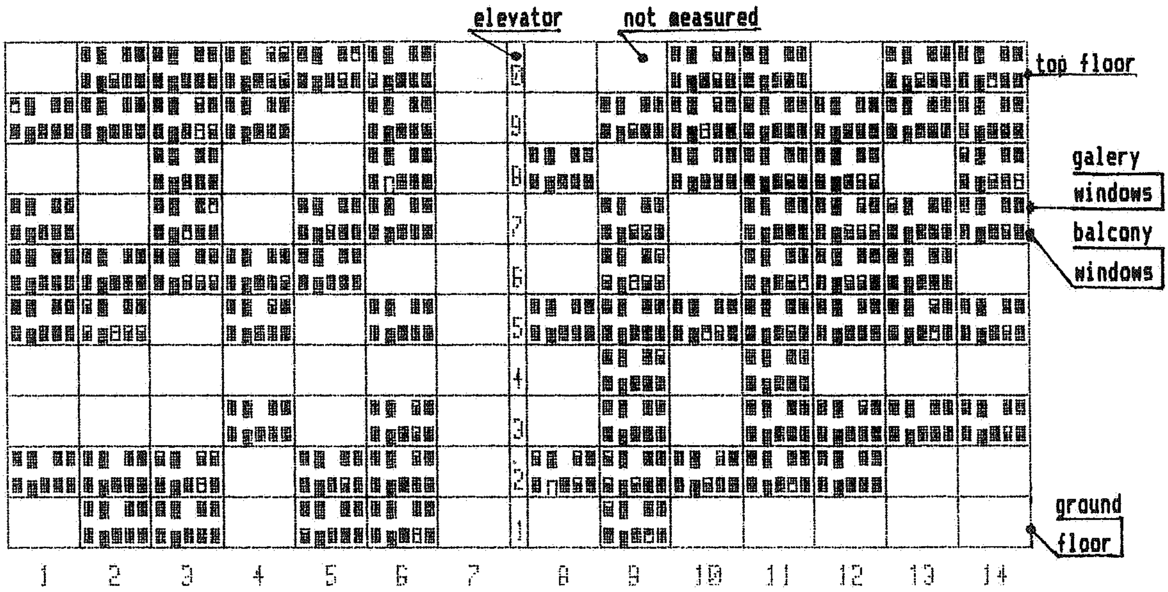


Figure 7 . Schematic view of the front facade as it appears on de CRT of the measuring computer in the building. The black rectangles represent the windows and doors. Filled black means closed.

In Figure 7 a printer dump is shown from de CRT of the measuring computer. It shows a schematic front view of the building in which the floors are numbered from 1 to 9 and 0 on the position of the elevator and the apartments from left to the right 1 to 14. The large blank rectangles are the apartments that are not included in the measurements. The others show on the top side small rectangles being the windows and the door on the galery side (front facade) and on the bottom the windows on the balcony side. In this way every window in the measurements is represented as a small rectangle that is filled when the window is closed (apearing black on the printer dump) and open or not filled when the window is open. This screen layout was very effective during the initial check on the functioning of all windows.

2. The Inquiry

On January 16 and 17, 1985, verbal inquiries have been set up in 70 of the 80 dwellings.
Most of the results are expressed in percentages of the total 70 dwellings.
Some results are:

Table 1 . The number of persons per dwelling.

	number of dwellings	
	%	n
1 person	9	6
2 persons	47	33
3 persons	26	18
4 persons	17	12
5 persons	1	1

total= 246 persons in 70 dwellings
n is the absolute number , 100 % = 70

Only in 6 dwellings are children under the age of 10. In 46% of the dwellings (32) one or more persons were older than 50.
In 71% of the dwellings one is home most of the time.
In 11% of the dwellings nobody is home for more than 5 hours a day.
In 4% of the dwellings this is the case during the weekends.
At night there is only one dwelling in which one is frequently absent.

The large bedroom on the balcony side is used in 95% of the dwellings.
In Table 2 is indicated which problems occur most frequently.

Table 2. Problems in the dwellings

objective, aspect	% dwellings with problems
the heating of rooms on the top floor	89 (of 9 dwellings)
odour from neighbours	70
condensation on windows	51
draught	50
noise from neighbours	39
discharge of cooking odours	36
stench from outside	36
cold temperature radiance	34
discharge of water vapour	24
discharge of sigarette smoke where one smokes	24
oudours from the own dwelling	17
heating of rooms (without the top floor)	16
cooling of rooms	14
noise from outside	14
noise from the own dwelling	13
moisture on walls	9
mould growth	7

Problems with the discharge of polluted indoor air and with the heating on the top floor here occur most frequently.

Table 3. The amount in which one is satisfied with the indoor climate

	%
very much satisfied	20
satisfied	59
not satisfied	6
just not satisfied	7
dissatisfied	6
very much dissatisfied	3

Table 4. The use of windows and the balcony door in the livingroom

hours open	vent light				pivot window				balcony door			
	cold		less cold		cold		less cold		cold		less cold	
per day	%	n	%	n	%	n	%	n	%	n	%	n
0-0.5	7	5	9	6	3	2	4	3	24	17	19	13
0.5-1					-		4	3	20	14	20	14
1 - 2	3	2	4	3	1	1	-		6	4	6	4
2 - 4					1	1	1	1	1	1	11	8
4 - 8	-		1	1	-		-		1	1	9	6
> 8	4	3	8	5	-		-		1	1	7	5
24	4	3	9	6	-		-		-		-	
total	19	13	30	21	6	4	10	7	54	38	71	50

cold = below 0 degree Celsius
less cold = above 0 degree Celsius
n is the absolute number , 100 % = 70

There has also been asked how wide windows are opened. For all windows and the balcony door it is valid that 25% of the windows that are open are opened about 20 mm and 75% was opened more wide.

In Table 5 the use of the windows in the large bedroom on the balcony side is indicated.

Table 5. The use of windows in the bedroom.

	ventlight left				ventlight right				pivot window left				pivot window right			
hours open	cold		less cold		cold		less cold		cold		less cold		cold		less cold	
per day	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n
< 0.5	8	5	5	3	6	4	2	1	8	5	3	2	9	6	5	3
0.5-1									5	3	12	8	17	11	17	11
1 - 2	2	1	2	1	8	5	3	2	9	6	6	4	9	6	6	4
2 - 4									3	2	2	1	5	3	11	7
4 - 8	-		-		-		3	2	3	2	3	2	6	4	8	5
> 8	-		3	2	3	2	11	7	5	3	12	8	15	10	32	21
24	8	5	14	9	38	25	55	36	-		-		-		-	
total	17	11	23	15	55	36	74	48	32	21	38	25	62	40	78	51

Left and right of the windows has been defined as seen from inside.

3. MEASUREMENTS OF WINDOW AND OUTSIDE DOOR POSITIONS

3.1. Method and setup for the measurements

For the being open or closed of the 1280 windows and outside doors reed relais and magnets are used. Per dwelling there are 7 openable windows and doors on the galery side and 9 on the balcony side.
A total of 16 per dwelling. On every window or outside door a magnet has been attached. The reeds are mounted on the window frame and every reed has parallel to its contacts a binary coded resistance. This means that the resistance values increase with a factor two.
The reedrelais are connected in series per facade of one dwelling.
From every facade of a dwelling a twin cable is connected to the data accquisition system placed in a room on the basement floor.
With the total series resistance for one facade it can be decoded which individual windows are open. An open window corresponds with an open reed so the parallel resistor is measured. A closed window means a closed contact and the resistor is short circuited. The hysteresis from open to close and vice versa amounts aproximately 15 mm on the window opposite the pivots.

The lowest resistance is 100 Ohm. The largest resistance on the galery side is 6400 Ohm and 25600 Ohm on the balcony side, the total series resistance on one facade is 25k5 and 51k1 Ohm.
The maximal tolerance in the series resistance is half the value of the smallest resistance i.e. 50 Ohm. This means that the inaccuracy of the largest resistances has to be less than 0.39 % on the galery side and 0.097% on the balcony side.
The resistances are selected and trimmed with a combination of fixed metal film resistors with the aid of the same multimeter that is used in the measurements controlled by a program which tells which resistor has to be added to trim. The maximum deviation is 11 Ohm on the galery and 19 and for some loops 25 Ohm on the balcony side (max 0,04%).

High demands are made on the quality of the multimeter for the (more than) 9 bit on site measurements. The total wire length is 25 km, all connected to the single ended scanner!
Adjustments are made for the temperature coefficient of the metalfilm and the resistance of the copper leads of the twin cable which is 16 to 30 Ohm.

The computer program that controls the measurements stores all window positions as 1280 bits at the start of each hour. During the hour only the changes within one dwelling are stored with the house number and the elapsed time since the beginning of the hour.
Every window will be measured every 15 to 20 seconds (rougly 240 times an hour).
Every 10 minutes 12 other channels are scanned. They include:
outside temperature, rainfall, sun shine, windvelocity near the facades, pressure difference over the building, the temperature of the central heating system supply, retour and the temperature in a ventilation shaft.
Every three hours the data is recorded on the disc, which can contain up to 15 days of measurements (=260 kbytes).

All measured resistances are compared with their last values on the same facade and dwelling. This is necessary when a window switches during the measurement time of the multimeter. This chance is small but it would result in a meaningless decimal resistance somewhere inbetween the range of the transient. Therefore when a change occurs the measurements loop a limited number of times until two sequential readings give the same window positions.

3.2. Results of the measurements

The positions of all 1280 windows and doors has been measured from week 48 in 1984 to week 19 in 1985. Some relatively small interruptions occurred caused by a disturbance in the main electrical supply, a disc failure and probably a scanner failure. The data that has been lost by this is not so important.
The available measurements represent the heating season quite well. Measurements have been made at cold and very cold (-15 degree Celsius) weather and also weather changes to relatively warmer periods are included.

3.2.1. A typical 24 hour pattern

In Figure 8 a typical pattern of the use of all 1280 windows and outside doors is represented. On the 10th of December 1984 the outside temperature has been 8 to 9 degrees (day and night) with a windspeed of 7 to 8 m/s from the South-West and West. During the day there was some sunshine given in in percentage of the longest possible time of sunshine on that day.

At night the number of open windows is very constant. Then there are 154 windows and doors open (12%). In the morning from 7:00 to 9:00 a morningpeak with 218 windows and doors (17%). During the morning a smooth decrease to the practically constant afternoon level (15% = 192 windows and doors). Then from 17:00 in the beginning a sharp decrease and further on gradual to the night level.

The number of windows and doors that switches shows the following things:
At night very little switchings. From 7:00 an increase of the number of windows that are closed and the number of windows that are opened. Moost of these changes are however door switchings, of which the greater part is always one opening followed by a closing.

On 12:00 a relative low number of changes. On 17:00 an increased level, probably caused by persons coming home. And after that a steady decrease with a minimum on the time of the 20:00 news on the television .
This is followed by some more switchings before going to sleep.

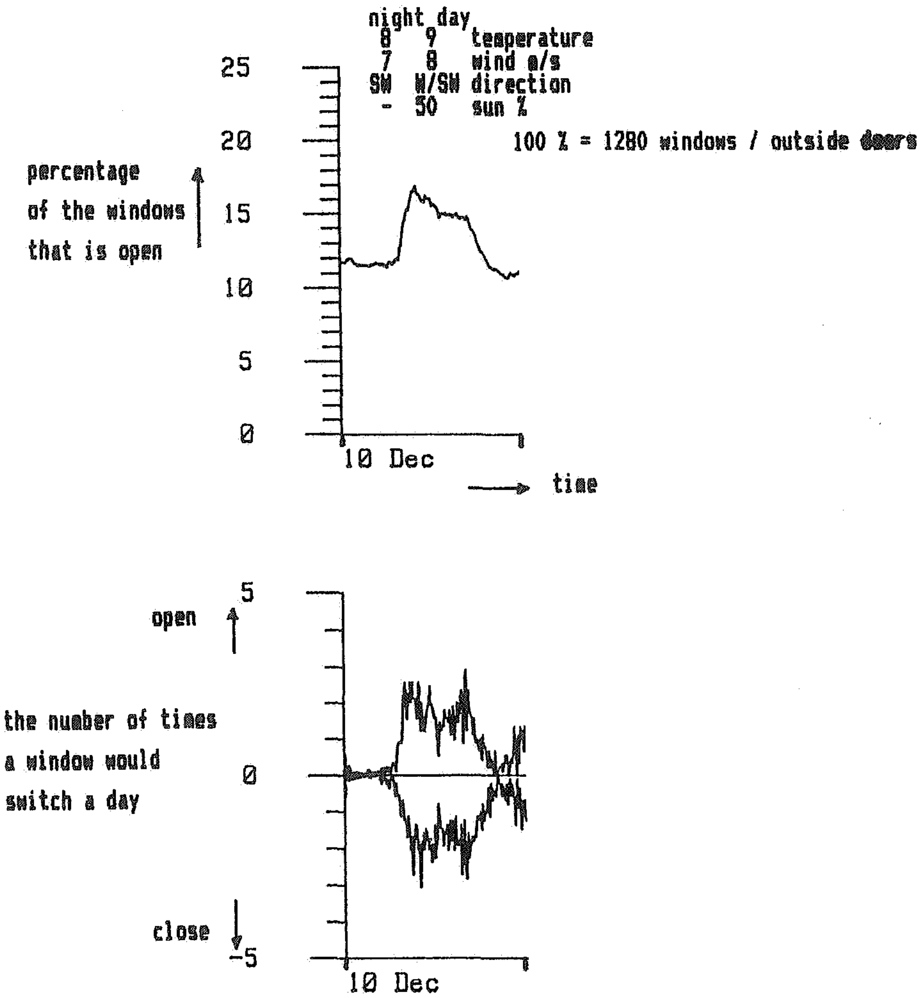


Figure 8 . A typical 24 hour pattern

The graphs of opening and closing windows seem to bee very symetrically. This is caused bij the relatively large number of door passages which they include.

Per day there is a mean of 35 switches per dwelling. It has to be noted that not all door passages can be detected when they occur in less than 15 to 20 seconds, as that is the time of one scan trough all 1280 windows. A door passage which takes 5 seconds has a 25% chance of being detected. And if it is detected it will seem from the recordings that it was open for 15 to 20 seconds, which is the time resolution in this setup.

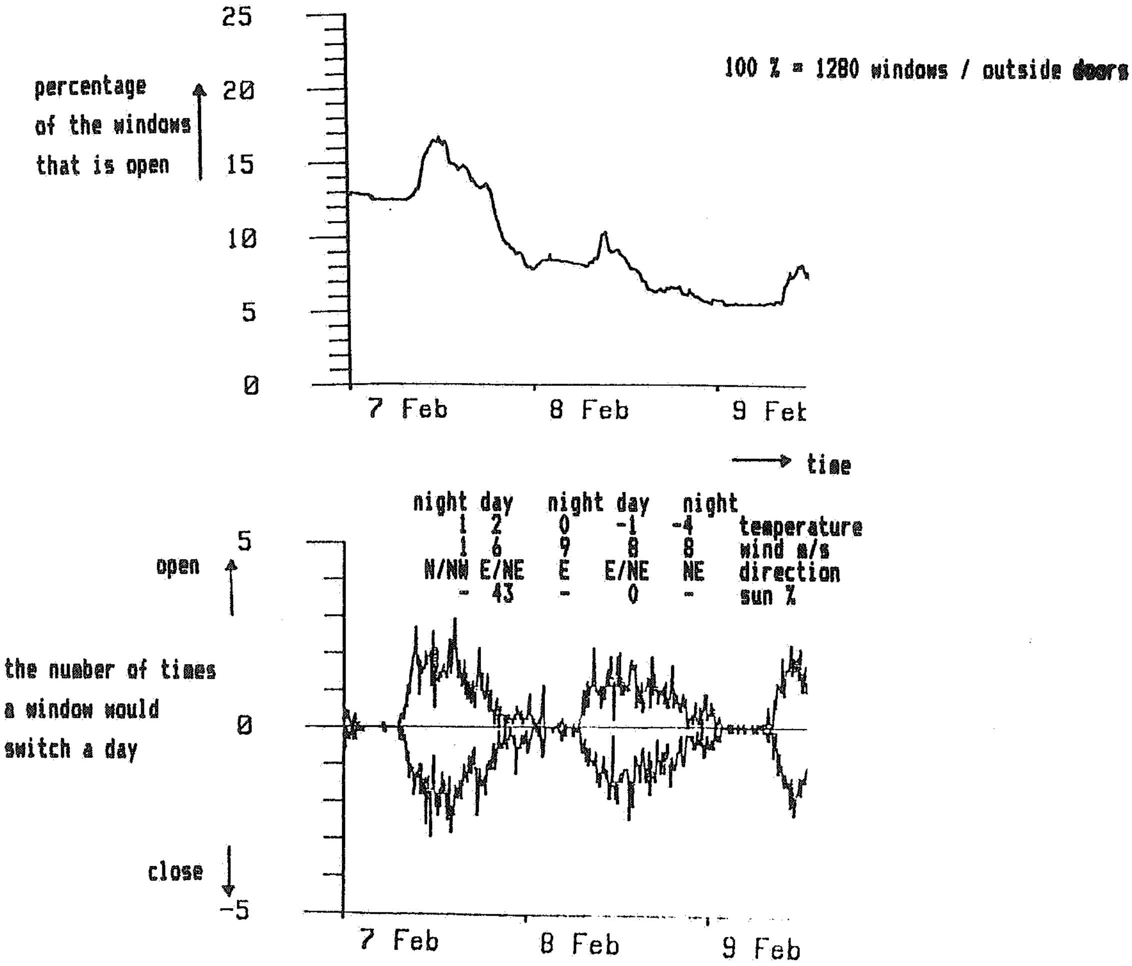


Figure 9 . A wheather change and the use of windows and doors.

3.2.2. A weather change

In Figure 9 the use of windows and doors is represented for the days 7,8 and 9 February 1985. This is a part of week 6. During these days there was a sudden weather change. The night levels are decreasing from 13 % to 8% and 6%, while the outside temperature is decreasing a little from 1 degree to 0 and -4 degrees. More important, however, is the change

in windspeed and direction from 1 m/s to 9 m/s on the night of February 8, while the wind direction changed from North-West to East. This means that the wind blows to the balcony facades where most of te used windows are situated.
The decreasing use of the windows is probably caused by the stronger wind which blows on the windows and not by the lowering of the temperature.
This weather change is the most pronounced one in the present measuring period.

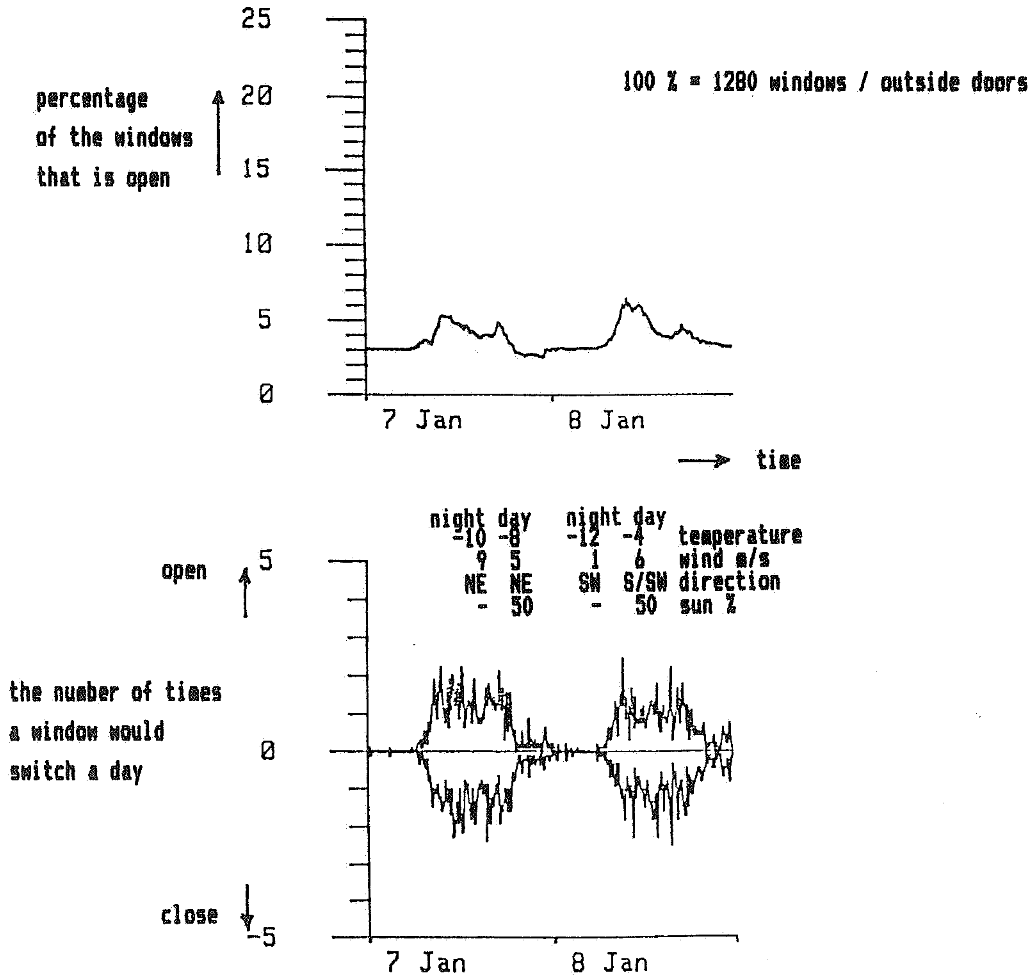


Figure 10. Cold winter days

3.2.3. <u>Cold winter days</u>

Even on these cold days (see Figure 10) with rather much wind from the North_East there are still 38 of the windows open (3%).
The day_night amplitude is obviously smaller then for instance on December 10 ,1984, (5 to 6% peak-peak). Here approximately 2% peak-peak.
Compared to December 10, 1984, there the number of of open windows is 3 to 4 times smaller.

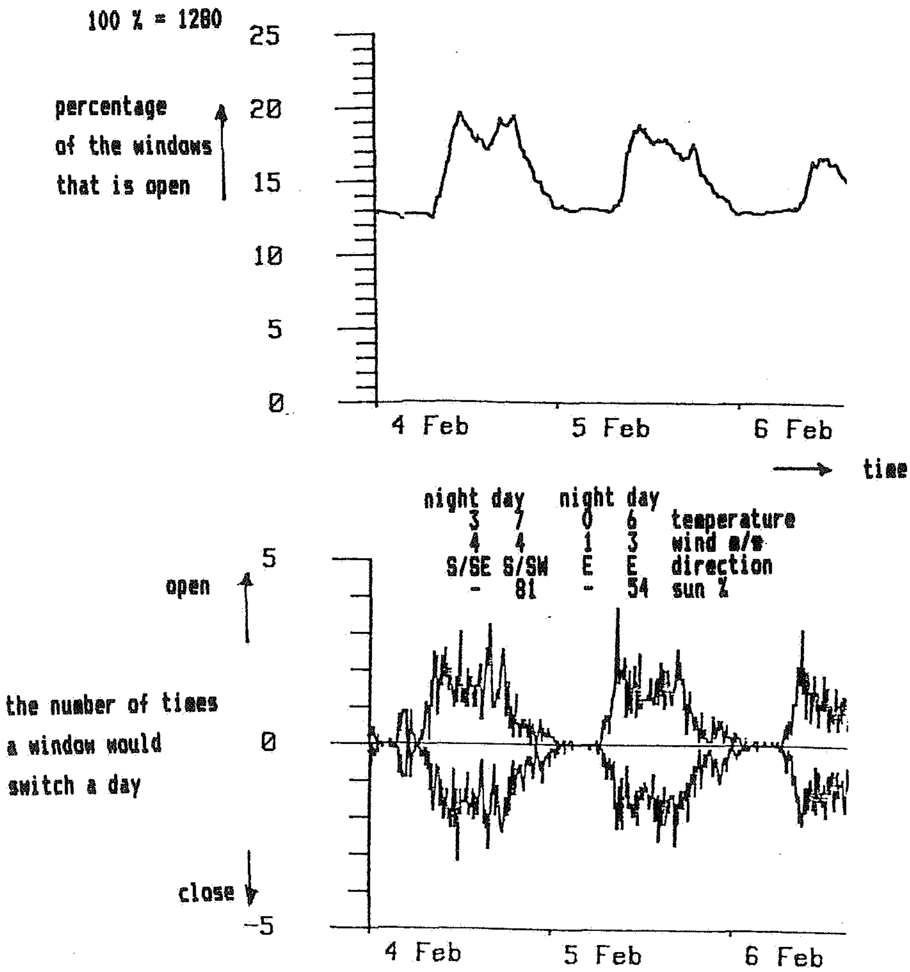


Figure 11. Mean winter days

3.2.4. Mean winter days

In Figure 11 the use of windows on Februari 4 and 5, 1985, is represented.
There is a fair amount of sunshine on these days.
The night level 13% (= 166) is practically the same as on December 10, 1984.
The day-night amplitude (peak-peak) is about 7% , with which the day level reaches 19 to 20 % (= 243 to 276 windows and outside doors open).
In the afternoon the balcony side is the leeward side and we believe that this results in a second peak of the number of open windows in the afternoon.

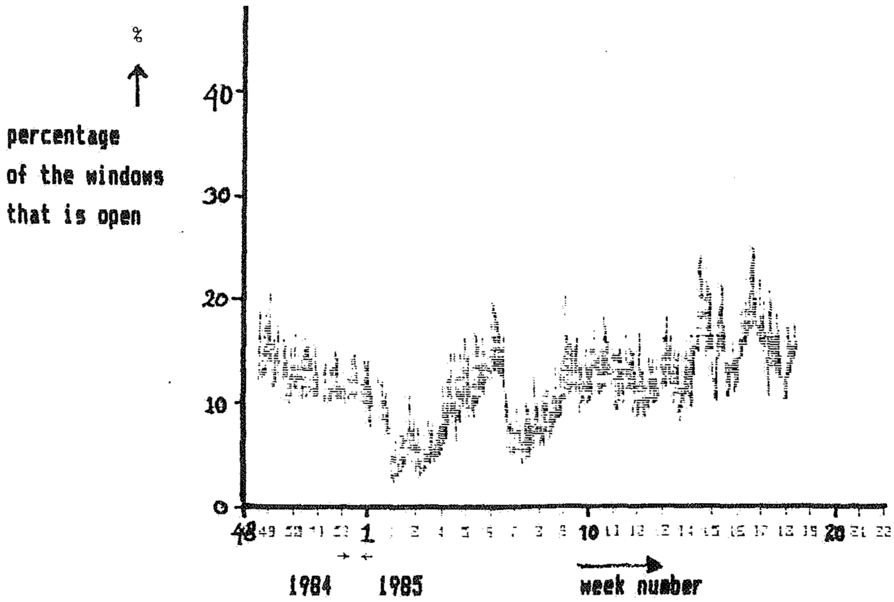


Figure 12. The precentage of open windows during the whole measuring time till week 19, 1985. (100%=1280 windows/outside doors)

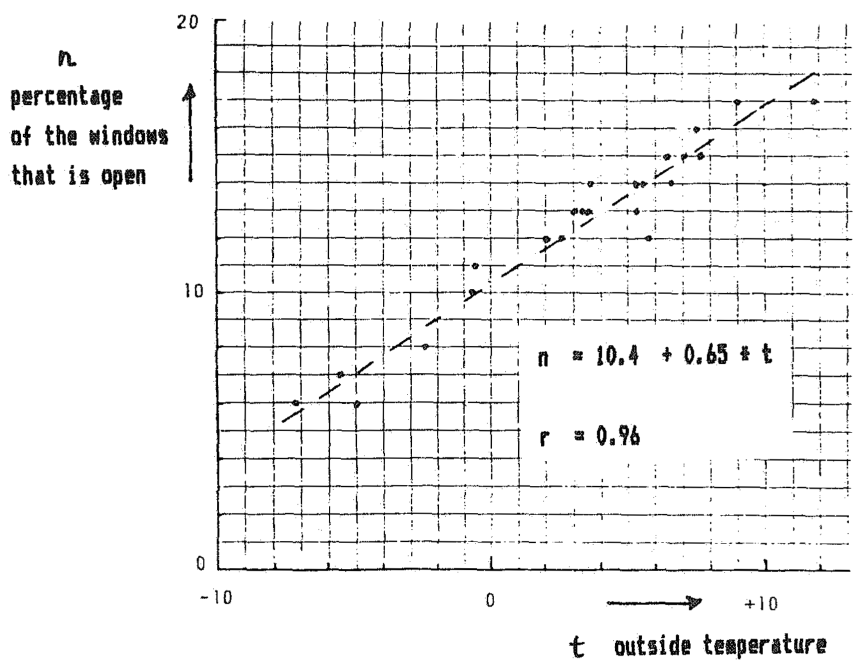


Figure 13. The relation between the weekly mean outside temperature and the weekly mean use of windows and outside doors. (100%=1280 windows/outside doors)

3.2.5 The course of the use of windows and doors during the heating season

In Figure 12 the course of the use of windows and outside doors is plotted against the week numbers. The very cold periods in the weeks 2, 3 and 6 and 7.

are obvious. The most striking weather change happens in week 6 .
In Figure 13 the relation between the outside temperature and the use of windows and outside doors are represented, both based on weekly mean values.
The following results can be noticed:

- there is a linear relation between the weekly mean number of windows that are open and the outside temperature.
- the correlation is very high for human behaviour (r=0.96).
- the deviations are caused by other weather and time influences.

It must be said that most wind influences are smoothed in the weekly means. This is probably the main reason for the high correlation of 0.96 .
Lyberg has summarised 8 reseachs on the use of windows and found that:

$$n * Dt = constant$$

in which n = the percentage of open windows
Dt= the temperature difference between inside and outside
the value of the constant is 1.8 to 2.6 .

When we take some point of the measurements form Figure 13, say 0 degrees and 10 %, it yields a constant of 2 with an inside temperature of 20 degrees C.
This value is fairly within the range 1.8 to 2.6 of Lyberg.
However the formula of Lyberg would result in a hyperbolic function in Figure 13.

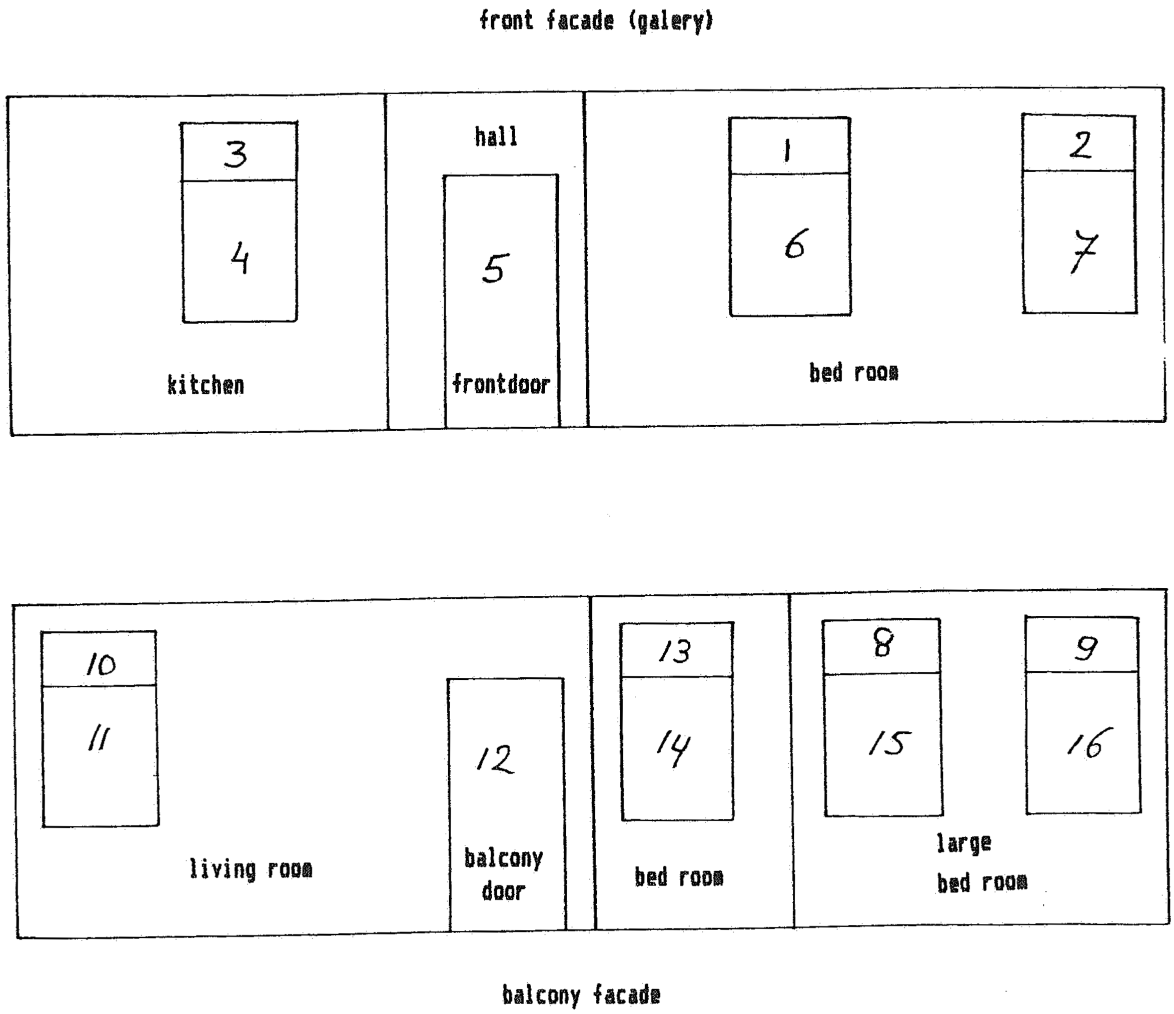


Figure 14. View on the facades. The numbers in the windows are the bit numbers in the computer and they are used in the following Figures and text.

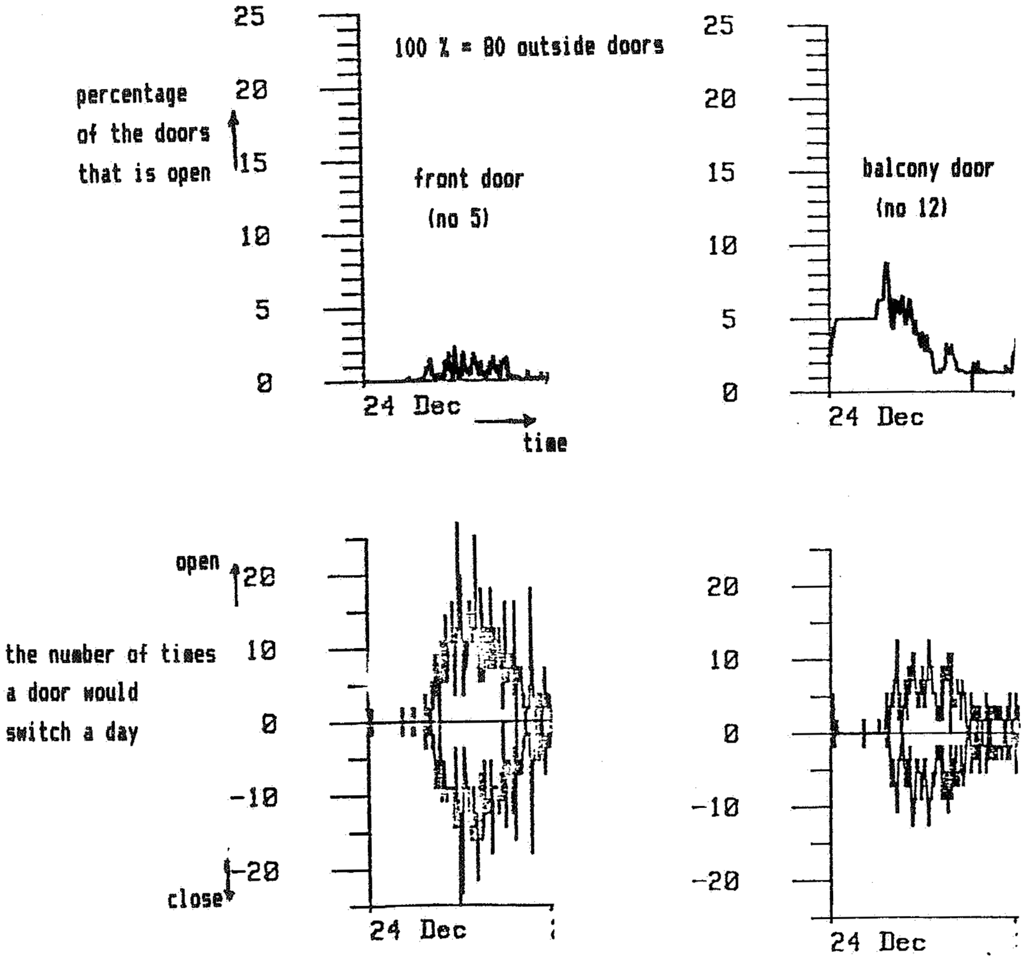


Figure 15. The use of outside doors. (100% = 80 doors)

3.2.6 The use of the outside doors

The being open and the number of switches for the front door and the balcony door differ a lot. The mean percentage of open is for the front door aprox 0.5 % . But we have to take in account that not all door passages can be detected because the whole scan along the 1280 windows is too slow (15 to 20 seconds) to catch them all. From the measurements it is 0.5 % open which means every front door is open for 7 minutes per day, but this will be more in reality. The balcony door is open about 3 % of the time. During this winter time there are 5% of the balcony doors open at night, surely set ajar. It appears that this door in the living room is used similar to the use of windows in the bedrooms. Before leaving the room windows are opened to air. When one is in the room less windows are open. But we have to admit that it is a small group that has this behaviour. The number of door passages of the front door is higer than that of the balcony door.

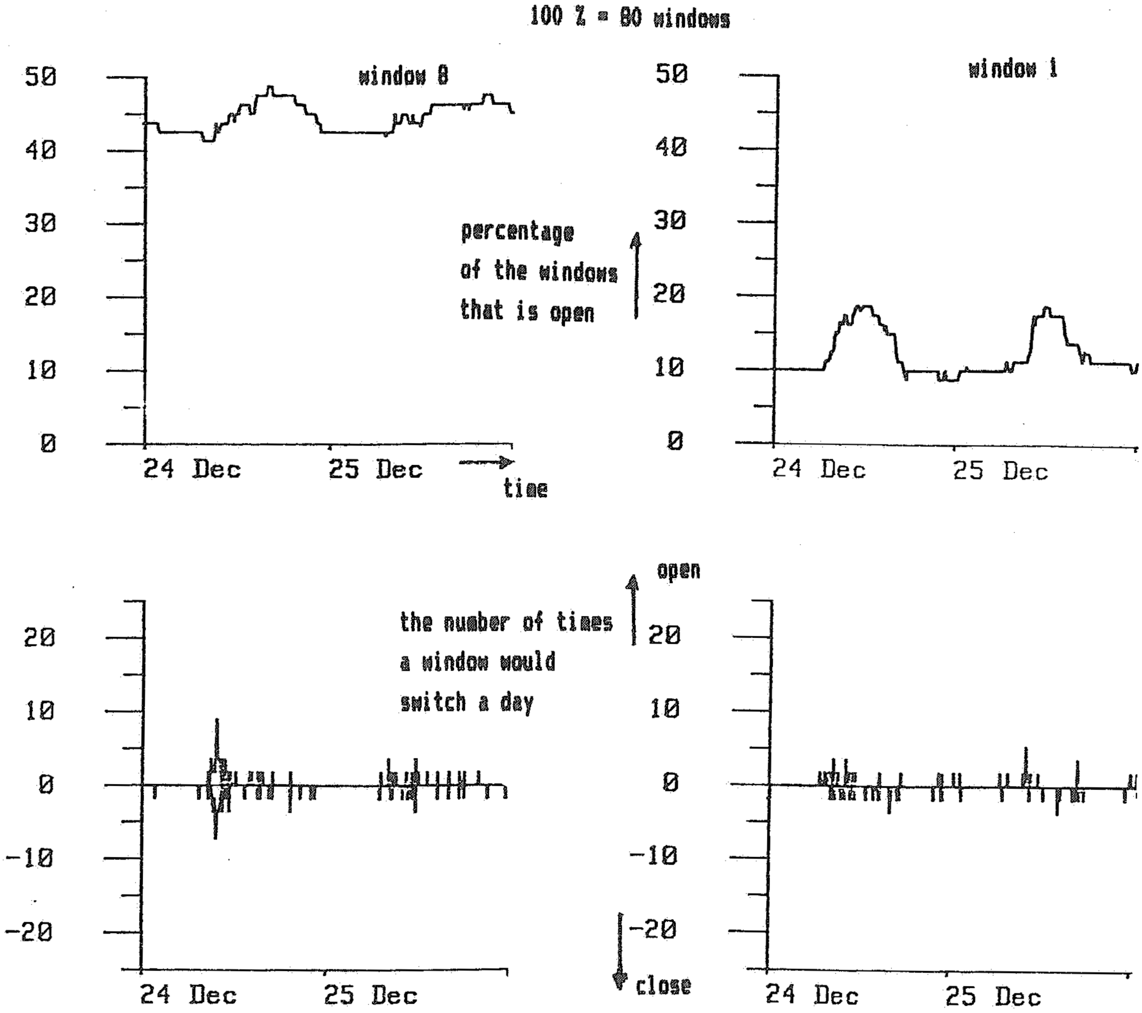


Figure 16. Ventlights on the balcony side and the galery side.

3.2.7. Ventlights on the balcony side and the galery side

A comparison of the use of the ventlights on the balcony side (no 8) and on the galery side (no 1) can be made from Figure 16.
Several aspects are causing this difference. Some of them are:

- rooms on the balcony side are more frequently used
- burgulary effect on the galery side
- the galery side is often the windward side

In Figure 20 it can be seen that in the bedrooms 2.5 times more ventlights are open on the balcony side than on the galery side.

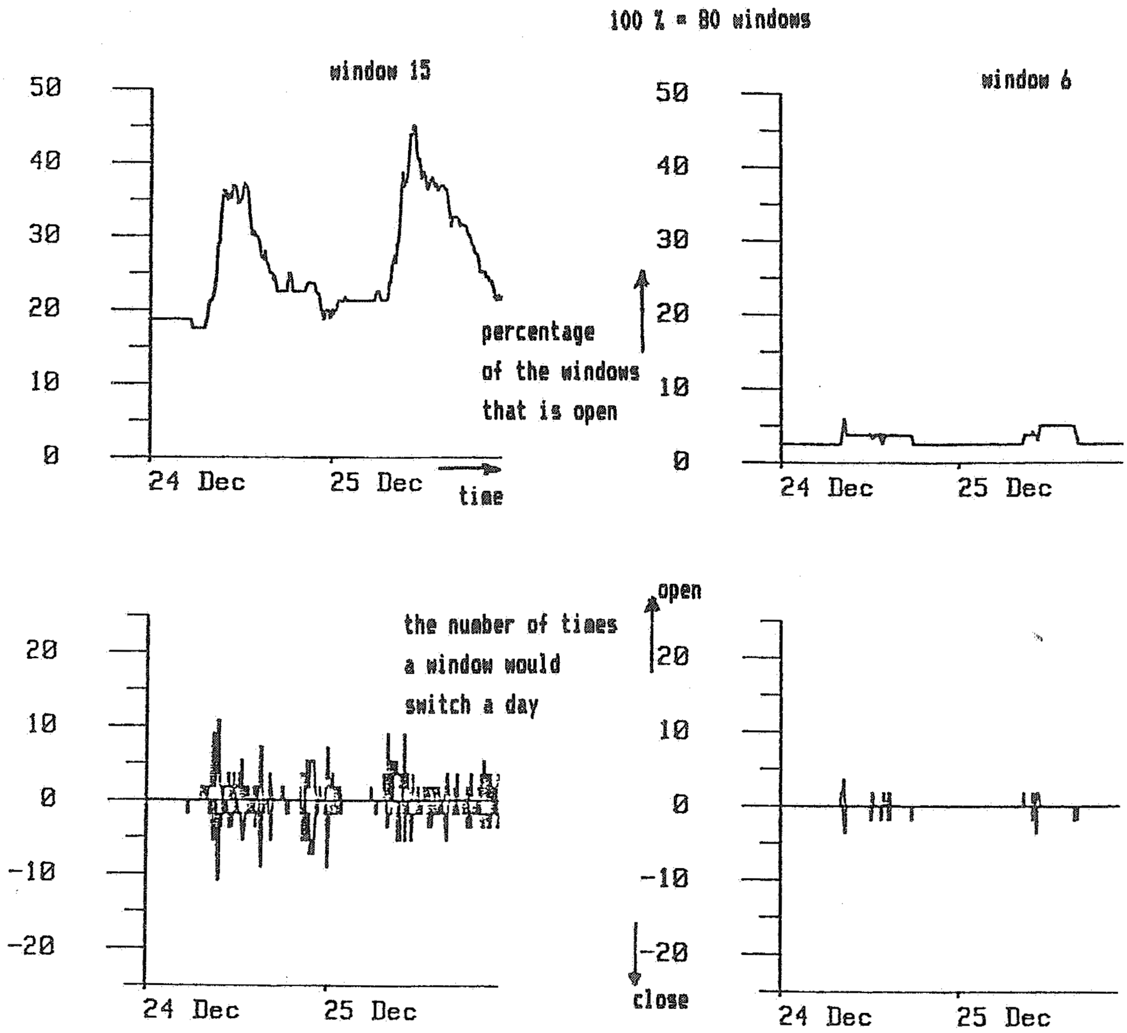


Figure 17. Pivot windows on the balcony side and the galery side.

3.2.8. Pivot windows on the balcony side and on the galery side

In Figure 17 the use of the pivot window on the balcony side (no 15) and one on the galery side (no 6) are represented for the same bedrooms as in the previous paragraph 3.2.7. .
The difference is large in the percentage open as well as in the number of switchings a day. Two windows on the galery side are continuously left open. They have fly grid in front.
On the balcony side the number of open pivot windows is more than 4 times greater than on the galery side (see Figure 20).

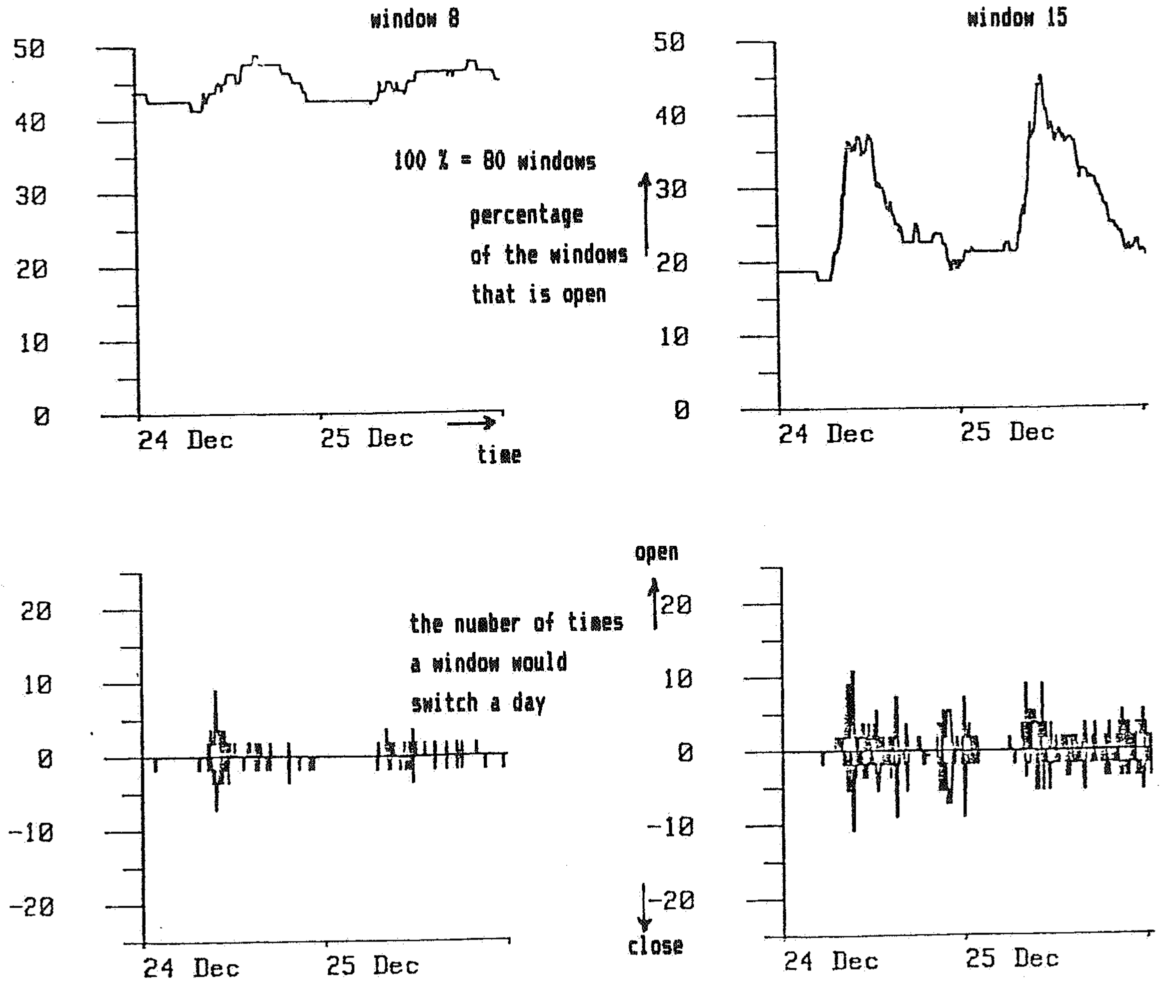


Figure 18 . The most widely used ventlight and the pivot window.

3.2.9 The most frequently used ventlight and pivot window.

In Figure 18 it can be seen that the day-night changes for the ventlight are smaller than those for the pivot window. Pivot windows show more switchings too. The ventlight has a larger percentage open (about 45 %) than the pivot window (20 % to about 40 %).

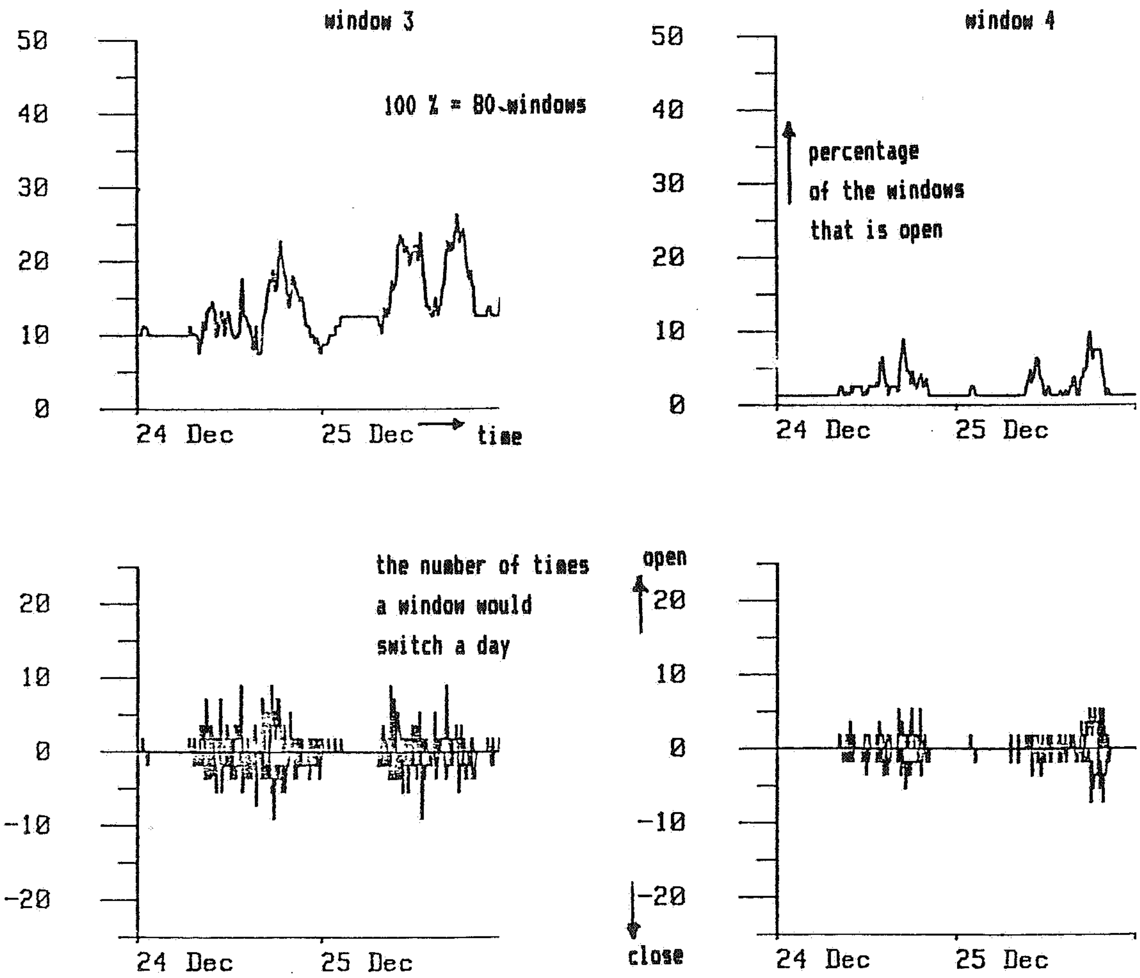


Figure 19 . The ventlight and the pivot window in the kitchen.

The kitchen is at the galery side. The peaks in the use of the windows coincide with the moments of preparing meals. One large window (no 4) is left open also at night, here again the one with a fly grid in front. The ventlight (no 3) is far more frequently used. The fact that December 24 is a special day for kitchen use does not show up in the use of the windows as we have seen in further analysis.

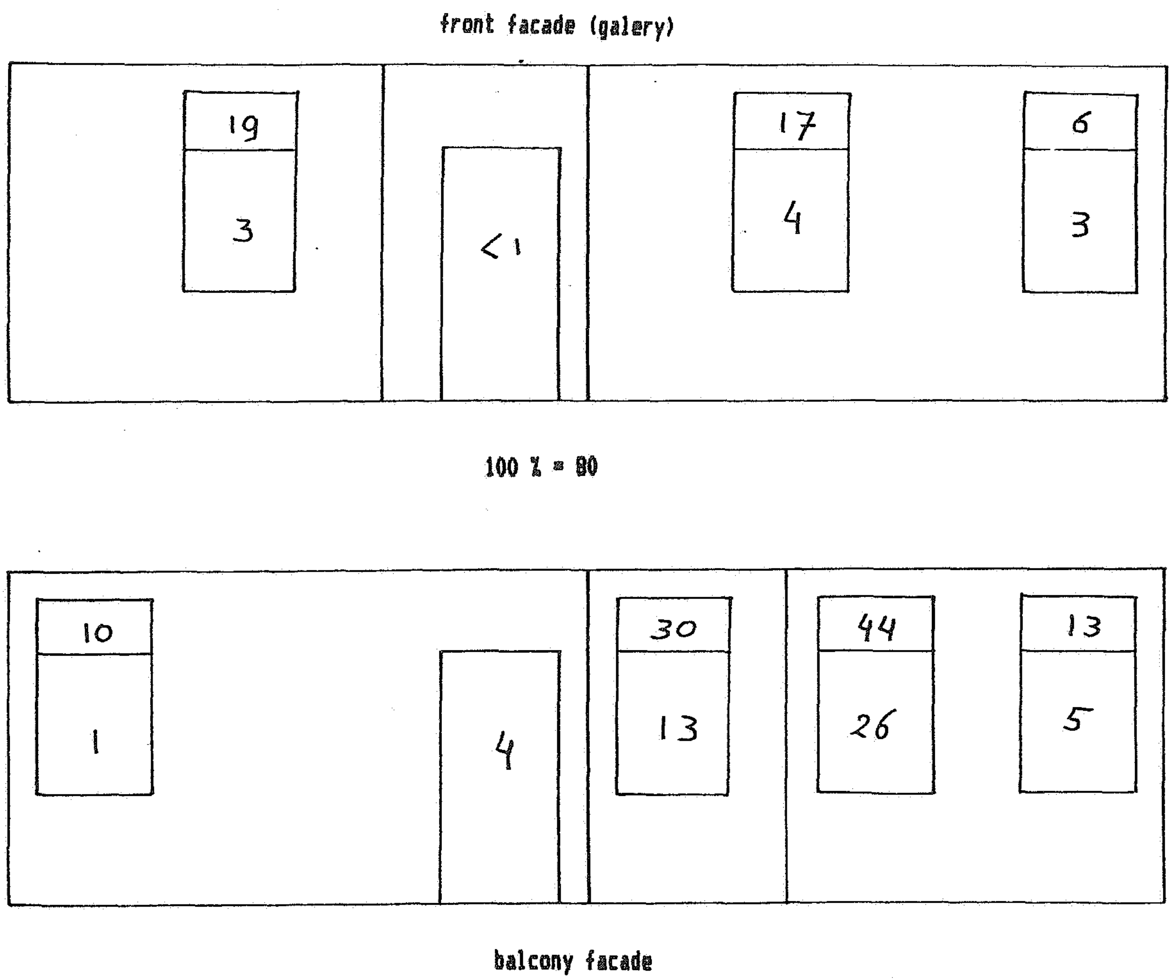
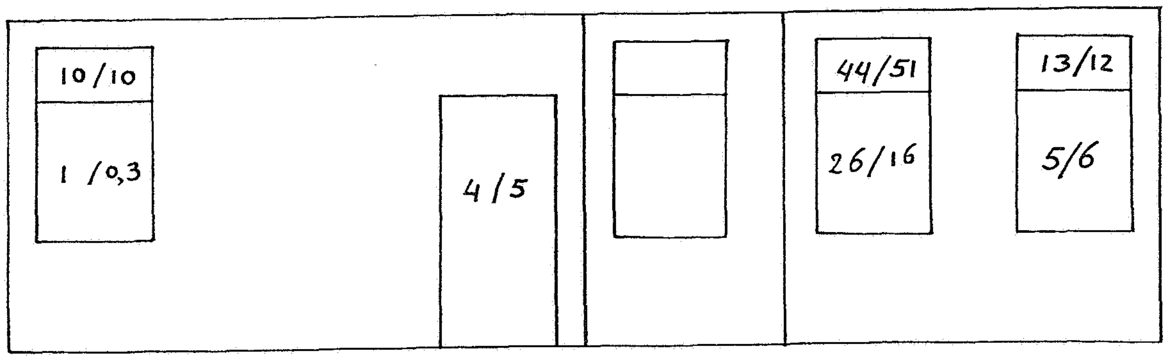


Figure 20. Overview of the mean use of windows in week 52 in % of the number of each specific window (= 80).

3.2.11. Overview of the use of windows and doors in week 52.

Figure 20 shows the mean percentage of open windows and doors in week 52. The livingroom for instance shows a 10% (=8 windows) use of the ventlight. This also means that for energy considerations every ventlight is open for 2.4 hours a day.

balcony facade



100 % = 80

Figure 21. Comparison of the results from the inquiry and from the measurements. The percentage of open windows is indicated. First the measurements/second the inquiry result.

4. Comparison of the results of the measurements and the inquiry

In a first superficial consideration we looked at what people say they do and what they do in reality. This is done by taking the mean of the results of the inquiry for cold and less cold weather, and the results of the measurements for week 52. This has been done for the large bedroom and the living room.

5. Preliminary energy consideration

From the inquiry it has been seen that 25 % of the windows and doors that are open are set ajar and the remaining 75 % is open more wide. Based on previous investigations [4] the contribution of all windows can be estimated. A shortcoming of this preliminary estimation is the neglection of the flow through the cracks of the windows when they are closed or the increase of the flow when they are opened on opposite facades. Here we take only the flow throuhg single windows and thus make a too low estimate.

The flow through the specific windows is calculated at a windspeed of 5 m/s and a temperature difference of 15 degrees and then multiplied by the percentage of open windows.

open ventlights	15	dm3/s
open pivot windows	27	dm3/s
open balcony doors	2	dm3/s
total	44	dm3/s

When we assume a reasonable ventilation at about 25 dm3/s (say 100 m3 per hour) then the mean overshoot amounts at least 19 dm3/s.
This means an unnecessary energy loss of about 5000 MJ (200 m3 dutch natural gas or about 200 litres of oil) per heating season.
For those that make an excessive use of the windows these figures will be a factor 3 higher.
It has to be noticed that, although not frequently mentioned in the inquiry, over heating of the rooms due to the one-pipe heating system and the large building mass will become a problem for some occupants when they will make less use of the windows.
Isolation of the heating pipes will solve the problem but since the heat from the pipes is not detected by the heat-cost-counters it can partly be considered as charge free heating, and it has to be doubted if occupants can be instructed to act more fundamental and thereby save energy for their fellow building occupants.

6. CONCLUSIONS

- The chosen measurement technique with reed relays, magnets and coded resistances operates even at low temperatures .
- The chosen measurement technique has the advantage of also measuring at night and bad visibility.
- There is a strong linear relation between the percentage open windows and the outside temperature when both are the weekly means.
- Weather changes can be seen distinctly in the recordings (figure 9).
- There is a clear difference in the use of windows on the balcony and the galery side.

- In week 52 in December 1984 can be seen (figure 20) :

  Ventlights are 14% open on the galery and 24 % on the balcony side
  Pivot windows are 3% open on the galery and 11% on the balcony side
  The front door is open 0.5% (with some tolerance) and the balcony door 4% .
  There is a characteristic pattern for the use of windows and doors.
  This pattern is different for example for the living room, bedroom and kitchen.
- Ventlights are opened or closed (changed) less frequently than large pivot windows.

- Pivot windows show a large morning peak to air the rooms. This takes 10 hours on the average for the windows that are opened.
- In a number of dwellings the balcony door is used to air the living room at night.
- From the inquiry the most important contribution is how far windows are opened, besides the motives for ventilation.
  25% of the open windows are set ajar, 75% is opened more wide.
- the most important motive for the use of windows is discharge of polluted indoor air.
- The agreement between the inquiry and the measurements for the percentage of open windows is good.
- an estimation for the unnecessary heat loss due to leaving windows too long open is 5000 MJ per dwelling per heating season (this is about 200 m3 dutch natural gas or 200 litres of oil, 1400 kWh)
  For the group that makes excessive use of the windows these figures can be up to 15000 MJ per dwelling per heatingseason (600 m3 gas , 600 litres oil or 4000 kWh).

Notice: These conclusions are determined for an appartment building and they will probably not be valid for other buildings or other locations.

7. LITERATURE

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