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A DETAILED STATISTICAL ANALYSIS OF WINDOW USE AND ITS EFFECT ON THE VENTILATION RATE IN 2400 BELGIAN SOCIAL HOUSES

P. WOUTERS
D. DE BAETS
Belgian Building Research Institute
Lombardstraat, 41
B - 1000 BRUSSELS
Belgium

SYNOPSIS

A large inquiry campaign began in 1985 on 100 social housing estates and 2,334 families were visited.
The housing estates were selected according to their age, location, type of building (dwelling/apartment) and heating system.

The main purpose of this paper is to explore the data received concerning window use in order to find the effect of the inhabitants on the ventilation rate. The summertime and wintertime situation was analysed and differences between individual dwellings and apartments were also investigated.

The results of this study can be summarized as follows :
- a rather good description of window use in Belgian social houses was achieved
- the impact of window use on the ventilation rate is estimated.

1. INTRODUCTION

A large inquiry campaign was conducted on some hundred social housing estates in Belgium. A total number of 2,334 families (1,115 individual dwellings and 1,219 apartments) were visited between January 1985 and November 1985. The major aims of the study were :
- to give a representative overview of building damage in the housing stock of the National Housing Society and to give indications for renovation opportunities (229,000 dwellings and apartments)
- to make a statistical representative database on inhabitants' behaviour with regard to ventilation and energy use.

This paper describes only a limited part of the data in relation to inhabitants' behaviour.

Firstly, a short overview of results concerning the motivation for opening and closing windows and doors is given. The major part then deals with the use of windows and doors in winter and summertime, i.e. position, frequency and duration of opening, and time of day. A combination of these data, with assumptions concerning air flow rates through open windows, have led to the estimation of air change rates.

2. MOTIVATION FOR OPENING AND CLOSING WINDOWS AND DOORS

People were asked to indicate the importance of several reasons for opening and closing windows. Four answers were possible. The possible answers and the percentages are given in Tables 1 and 2.

	Very important (3)	Impor-tant (2)	Less important (1)	Not important (0)	Average
-to air	53	42	3	2	**2.47**
-to remove bad smells	40	41	6	13	**2.08**
-to avoid condensation	17	42	14	27	**1.49**
-to remove smoke	13	27	18	41	**1.11**
-to renew stained air by heating	10	26	23	40	**1.05**
- to reduce temperature	6	20	23	49	**0.81**

Table 1 - Reasons for opening windows (% of answers).
The last column gives the weighted average of the 4 answers; where
- very important = 3
- important = 2
- less important = 1
- not important = 0.

	Very important (3)	Impor-tant (2)	Less important (1)	Not important (0)	Average
-to maintain the inside temperature	64	31	2	2	**2.56**
-to protect against bad weather	37	43	5	15	**2.02**
-to avoid draught	34	42	9	16	**1.95**
-to preserve safety	34	31	10	24	**1.74**
-to avoid outside pol-lution	16	32	24	27	**1.36**
-to preserve privacy	13	28	25	34	**1.20**
-to avoid outside noise	14	24	25	37	**1.15**

Table 2 - Reasons for closing windows or to hold them closed (% of answers, total of each line is 100 %).
The last column gives the weighted average of the 4 answers; where :
- very important = 3
- important = 2
- less important = 1
- not important = 0.

3. HOW DO PEOPLE USE WINDOWS ?

3.1. Basic analysis

Four questions were asked with regard to the window use in different rooms. A total of 8,955 answers for wintertime use and 9,323 for summertime use were given.

3.1.1. **Question 1 : Position of the window**

Table 3 gives three possibilities and the number of answers (use in winter time and use in summertime) in percentage and in absolute figures (between brackets).

Answer	WINTER	SUMMER
⊣ Window never open	**27** (2,460)	**9** (880)
⊢ Window ajar	**53** (4,700)	**33** (3,090)
⊢ Window wide open	**20** (1,790)	**57** (5,350)

Table 3 ⊢ Number of rooms with such window use (Percentage and absolute number)

A significant difference between summer and winter exists : 1 of the 4 rooms is never ventilated in winter, while this figure becomes only 1 of the 10 rooms in summer. Preference is given to windows ajar in winter and wide open in summer.

3.1.2. **Question 2 : How many times do you open the window ?**

Table 4 gives the results. The percentages are indicated with reference to the number of rooms where windows and doors are opened.

Answer	WINTER	SUMMER
⊢ Several times a day	**6** (380)	**12** (850)
⊢ Once a day	**81** (5,140)	**82** (5,950)
⊢ Several times a week	**7** (420)	**4** (290)
⊢ Once a week	**6** (400)	**3** (190)

Table 4 ⊢ Frequency of window opening (%)

Interpretation : 80 % of windows are ventilated once a day.
No significant difference exists between summer and wintertime.

3.1.3. **Question 3 : What is the average opening time ?**

Four answers were possible. "Continuously" is related to the fourth question.

Answer	WINTER	SUMMER
⊢ A few minutes	**21** (1,380)	**3** (280)
⊢ Less than one hour	**46** (2,990)	**8** (680)
⊢ Several hours	**12** (810)	**21** (1,760)
⊢ Continuously during the period indicated in Table 6	**21** (1,340)	**68** (5,740)

Table 5 ⊢ Average opening time (%)

Interpretation : As one can expect, the opening time in winter is rather short; in 66% of the cases less than 1 hour.
In summertime, 90 % of the windows are open at least several hours a day.

3.1.4. **Question 4 : At what time of the day are the rooms ventilated ?**

Nine answers were possible (see Table 6)

Answer	WINTER	SUMMER
- Early in the morning	3 (300)	2 (220)
- In the morning	32 (2,860)	6 (540)
- At noon	4 (400)	2 (180)
- In the afternoon	5 (480)	3 (260)
- In the early evening	1 (100)	0 (30)
- In the evening	2 (230)	1 (110)
- During the day	19 (1,740)	58 (5,490)
- At night	29 (2,640)	11 (1,070)
- Day and night	4 (330)	16 (1,540)

Table 6 - Distribution (in %) of time of the day for ventilating the room.

In the case of wintertime, the morning period is frequently answered, contrary to summertime where preference is given to "during the day".

Remark :
Earlier studies showed that the reliability of the information given by inhabitants can be doubtful. One should therefore be careful and pay more attention to relative differences than to absolute figures.

3.2. Detailed analyses of window use as a function of the type of room

3.2.1. How many windows/doors are opened and in which position ?

Table 7 gives an overview of the distribution of the answers for six different rooms and for the whole dwelling. A separation between individual dwellings and apartments has also been made.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
1. Window never open						
living room	52	57	46	18	22	14
kitchen	26	33	19	6	7	4
bathroom	31	27	42	12	9	17
bedroom 1	8	8	7	3	2	3
bedroom 2	19	16	22	9	7	10
bedroom 3	20	20	20	7	6	10
entire house	**27**	**29**	**25**	**9**	**10**	**9**
2. Window ajar						
living room	37	29	46	23	18	28
kitchen	62	50	73	40	28	51
bathroom	50	48	55	43	37	57
bedroom 1	66	57	72	38	27	46
bedroom 2	55	48	61	31	20	40
bedroom 3	50	49	53	27	23	36
entire house	**53**	**45**	**62**	**33**	**26**	**42**
3. Window wide open						
living room	11	14	7	59	60	58
kitchen	12	17	7	55	65	45
bathroom	19	25	3	45	54	25
bedroom 1	27	35	20	60	71	51
bedroom 2	27	36	17	61	73	50
bedroom 3	30	31	27	66	71	53
entire house	**20**	**25**	**13**	**57**	**64**	**50**

Table 7 - Number of rooms with this window use (%).

Interpretation

- For the entire house
  - There is no significant difference between apartments and dwellings with regard to the number of rooms which are never ventilated.
  - A significant difference exists in preference of window position : preference is given to the position "ajar" for apartments :
    wintertime : almost 85 % (62 / (62+13)) of the windows are opened "ajar" in the case of apartments, while 65 % (45 / (45+25)) was the case for individual dwellings.
    summertime : 45 % of the windows are opened "ajar" for apartments, 30 % for individual dwellings.

- For the individual rooms
  - The number of living rooms which are never ventilated in wintertime is much higher than the average figure for the entire house : 52 % against 27 %.
    57 % of the living rooms in individual dwellings are never ventilated.
  - The bedrooms are more ventilated than the average room.
    90 % of all the principal bedrooms are ventilated in wintertime.
  - The window position "wide open" is very seldom used in wintertime in the case of living rooms, kitchens and bathrooms of apartments.

3.2.2. **Estimation of opening times**

The collected information did not give us direct information about the duration of ventilation, and this information is important for calculations.
The answers were therefore translated into duration times.
It is evident that such translation is rather subjective.

ASSUMPTIONS :

- Frequency

  Several times a day/a week → we suppose twice a week

- Duration time

. a few minutes	→	0.25 hour	
. less than 1 hour	→	0.75 hour	
. several hours	→	2 hours	
. continuously	→	early in the morning	= 2 hours
		in the morning	= 2 hours
		at noon	= 3 hours
		in the afternoon	= 3 hours
		in the early evening	= 3 hours
		in the evening	= 3 hours
		during the day	= 10 hours
		at night	= 10 hours
		day and night	= 24 hours

Table 8 gives all the results.

Remark : the weighted average opening time has been calculated as follows :

ex. : living room, all houses :

Table 7 : - 52 % are never opened
- 37 % are opened ajar
- 11 % are wide open.

Table 8 : - average opening time ajar = 1,0 h/day
- average opening time wide open = 1,3 h/day.

→ weighted average opening time =
(0,52 x 0 + 0,37 x 1 + 0,11 x 1,3) h/day =
0,51 h/day → 0,5 h/day.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
1. Weighted average opening time for all the rooms						
- living room	0.5	0.4	0.7	6	5	7
- kitchen	1.1	0.9	1.4	7.0	6	7.5
- bathroom	1.4	1.6	0.9	7.0	7.5	6
- bedroom 1	3.8	4.0	3.7	11.5	11.5	11.5
- bedroom 2	2.9	2.9	2.9	10.0	10	10
- bedroom 3	2.4	2.2	2.8	9.5	9.5	10.5
- **entire house**	**2.0**	**2.0**	**2.1**	**8.5**	**8**	**9**
2. Window ajar						
- living room	1.0	0.8	1.2	6	5	6.5
- kitchen	1.5	1.2	1.8	6.5	6.5	6.5
- bathroom	2.1	2.5	1.5	7	7.5	6.5
- bedroom 1	4.1	4.5	3.8	12	12.5	12
- bedroom 2	3.4	3.3	3.5	10.5	10.5	10.5
- bedroom 3	2.7	2.7	2.7	10.5	8.5	13.5
- **entire house**	**2.8**	**2.9**	**2.6**	**9**	**9**	**9**
3. Window wide open						
- living room	1.3	1.0	1.8	8	6.5	9.0
- kitchen	1.7	1.6	1.9	8	6.5	9.5
- bathroom	1.6	1.6	1.3	8.5	8.5	9.0
- bedroom 1	4.3	4.2	4.5	12	11.5	12
- bedroom 2	3.7	3.6	4.1	11	11	11
- bedroom 3	3.4	2.8	5.1	10.5	10.5	11
- **entire house**	**3.0**	**2.6**	**3.8**	**9.5**	**9**	**10.5**

Table 8 - Average duration time of window opening as function of several parameters (hours/day)

Interpretation

Table 9 gives the results for the entire house.

	WINTER			SUMMER		
	D + A	Dwell.	Ap.	D + A	Dwell.	Ap.
Window ajar	2.8(53)	2.9(45)	2.6(62)	9 (33)	9 (26)	9 (42)
Window wide open	3.0(20)	2.6(25)	3.8(13)	9.5(57)	9 (64)	10.5(50)
Weighted average	**2.0**	**2.0**	**2.1**	**8.5**	**8**	**9**

Table 9 - Average opening time for the 2 window positions and weighted average (the figures between brackets are the frequency of occurance - %) (hours/day).

- The average opening time of all the windows in a house is 2 hours a day in wintertime and 8 hours a day in summertime.
- Higher values are found for bedrooms and lower values for living rooms and kitchens.
- The opening times for windows "ajar" are more or less the same as for windows "wide open".

- The average opening time for the whole house is 8 % in wintertime and about 35 % in summertime.
  These values can be compared with the formulae of Lyberg [1] and De Gids [2]

  Lyberg : $H.\Delta T = C^{te} = 180 \ldots 260$ (hyperbolic)
  De Gids : $H = A + B\,T$
  where $A \simeq 10$ and $B \simeq 0.65$
  H = percentage of open windows (%)
  T = external temperature (°C)
  ΔT = temperature difference between inside and outside = $T_i - T_e$ (i)

  For Belgium :
  T_i = 18°C
  T_e = 2°C (average temperature January)
  = 15°C (average temperature Summer)

  or De Gids : H = 11 % (wintertime) and 20 % (summertime)
  Lyberg : H = 11 to 16 % (wintertime)

  Our data for wintertime are lower than the results obtained from the 2 formulae; for summertime these data are higher than the figure of De Gids. (the formulae of Lyberg are not viable for small values of ΔT).

3.2.3. Estimation of the increase in ventilation rates due to window use

- An estimation of the effect of inhabitants' behaviour on the ventilation rate is possible.
  Let us suppose :
  . air flow rates through an open window :
  - window ajar (6 cm) : 50 to 150 m^3/h (Knöbel) [3]
  - window wide open (0.5 m^2) : 200 to 300 m^3/h (Pfaff) [4]
  Rem. : we have supposed the same airflows in wintertime and summertime taking into account the high uncertainty of the assumed airflow rates
  . dwelling/apartment - volume : 200 m^3.

The application of this assumption to the information obtained for all the rooms allows an estimation of the increase in ventilation rate due to the occupants n_{occ} :

$$n_{occ} = \left(\frac{\sum \text{TIME} \times Q_{W,min}}{24 \times \text{VOL}} + \frac{\sum \text{TIME} \times Q_{W,max}}{24 \times \text{VOL}} \right) / 2$$

where :

n_{occ} : increase in ventilation rate due to occupants (ac/h)

$\sum$: addition for all the rooms

TIME : estimated duration of open windows (h/day)

Q_w : estimated air flow through open windows (m^3/h) (ajar/wide open)

max : maximum air flow (150 m^3 for ajar and 300 m^3 for wide open)

min : minimum air flow (50 m^3 for ajar and 200 m^3 for wide open)

VOL : air volume of the house (m^3)

Table 10 gives the average values and median values.

	Dwellings+apartm.		Dwellings		Apartments	
	mean	median	mean	median	mean	median
WINTER	0,26	0,10	0,31	0,14	0,21	0,09
SUMMER	1,5	1,2	1,7	1,3	1,3	1,0

Table 10 - Mean and median values for n_{occ} (ac/h).

A distribution of the increase in ventilation rates is given in Figs. 1 to 3.

Interpretation

- The influence of the window use on the ventilation rate can be analysed by using mean values or median values.
  Table 10 shows that there exists a significant difference between them.
  . mean : weighted average of all the values
  . median : the average value of the samples when arranged in order of magnitude.

- The mean value for n_{occ} in winter is 0,26 ac/h; this means that window use increases on average with a ventilation rate of 0,26 ac/h. The median, which is 0,10 ac/h, means that n_{occ} is less than 0,10 ac/h, in 50 % of all the cases.

- Practical conclusion :
  . the window use in winter signifies for 50 % of the houses an increase in ventilation rate of less than 0,10 ac/h.
  . a very significant difference for n_{occ} between dwellings and apartments exists : 0,31 ac/h versus 0,21 ac/h.
  This is due to the fact that windows ajar are much more common in apartments than in dwellings.
  This result might be somewhat misleading because it is clear that the air flow through an open window in an apartment building at the 5th floor is higher than the same open window at street level in a dwelling.
  . the results in summertime indicate that n_{occ} is between 1 and 1,5 ac/h.
  . Table 11 gives the percentage of families where n_{occ} is higher in winter than the indicated values.

	> 0,25	> 0,50	> 0,70	> 1,00
All houses	28	15	11	7
Dwellings	32	17	13	9
Apartments	23	12	8	5

Table 11 - % of families with n_{occ} in winter above the indicated value (ac/h).

3.2.4. **Practical calculation data**

The rather wide variation in figures does not allow us to realize a very clear formula for the expression of window use. The following 3 tables try to reflect the main trends in the results.

		WINTER			SUMMER		
		Dwell.	Average	Ap.	Dwell.	Average	Ap.
NE-	whole house		30			10	
VER	living room	+	50	-		20	-
	bedrooms		15			5	
AJAR	whole house	-	50	++	-	30	++
	living room	--	40	+		35	
	bedrooms	-	55	+		35	
WIDE	whole house	+	20	-	++	55	-
OPEN	living room	+	10	--	++	60	--
	bedrooms	+	30	-	++	60	--

Table 12 - Simplified table for average window use (in %)

\+ = 5 to 10 % more than average

++ = more than 10 % above average

\- = 5 to 10 % less than average

-- = more than 10 % beneath average.

		WINTER			SUMMER		
		Dwell.	Average	Ap.	Dwell.	Average	Ap.
AVERAGE FOR ALL ROOMS	whole house	⌐	2	+		8	
	living room		0.5			6	
	bedrooms		3			10	
ROOM WITH OPEN WINDOWS	whole house	⌐	3	+			
	living room		1				
	bedrooms		4.0				

Table 13 - Simplified table for average opening time of windows (hours/day) + = at least 20 % higher than average ⌐ = at least 20 % less than average

	WINTER		SUMMER	
	AJAR	WIDE OPEN	AJAR	WIDE OPEN
Less than 15 min.	4	2	1	1
15 to 30 minutes	10	2	1	1
30 min. to 1 hour	20	8	4	4
1 to 3 hours	8	4	8	8
3 to 6 hours	1	1	1	4
6 to 12 hours	4	2	15	30
More than 12 hours	2	2	4	10
Not ventilated	30		10	

Table 14 - Simplified table for distribution estimation of window opening times (% of all the rooms).

4. CONCLUSION

The main conclusions of this study are :

- some 30 % of all the windows were never opened in wintertime and some 10 % in summertime. Higher values are found for the living room and lower ones for the bedrooms.

- There is a preference for the position "ajar" in wintertime and "wide open" in summertime. In apartments the position "ajar" occurs more frequently.

- The average opening time for all the windows is some 2 hours in winter and some 8 hours in summer.

- This behaviour data in combination with a few assumptions lead to an estimated average increase in the ventilation rate for wintertime of 0.25 ac/h with somewhat higher values for dwellings and somewhat lower values in apartments. However, for 50 % of the families this increase is below 0,1 ac/h.

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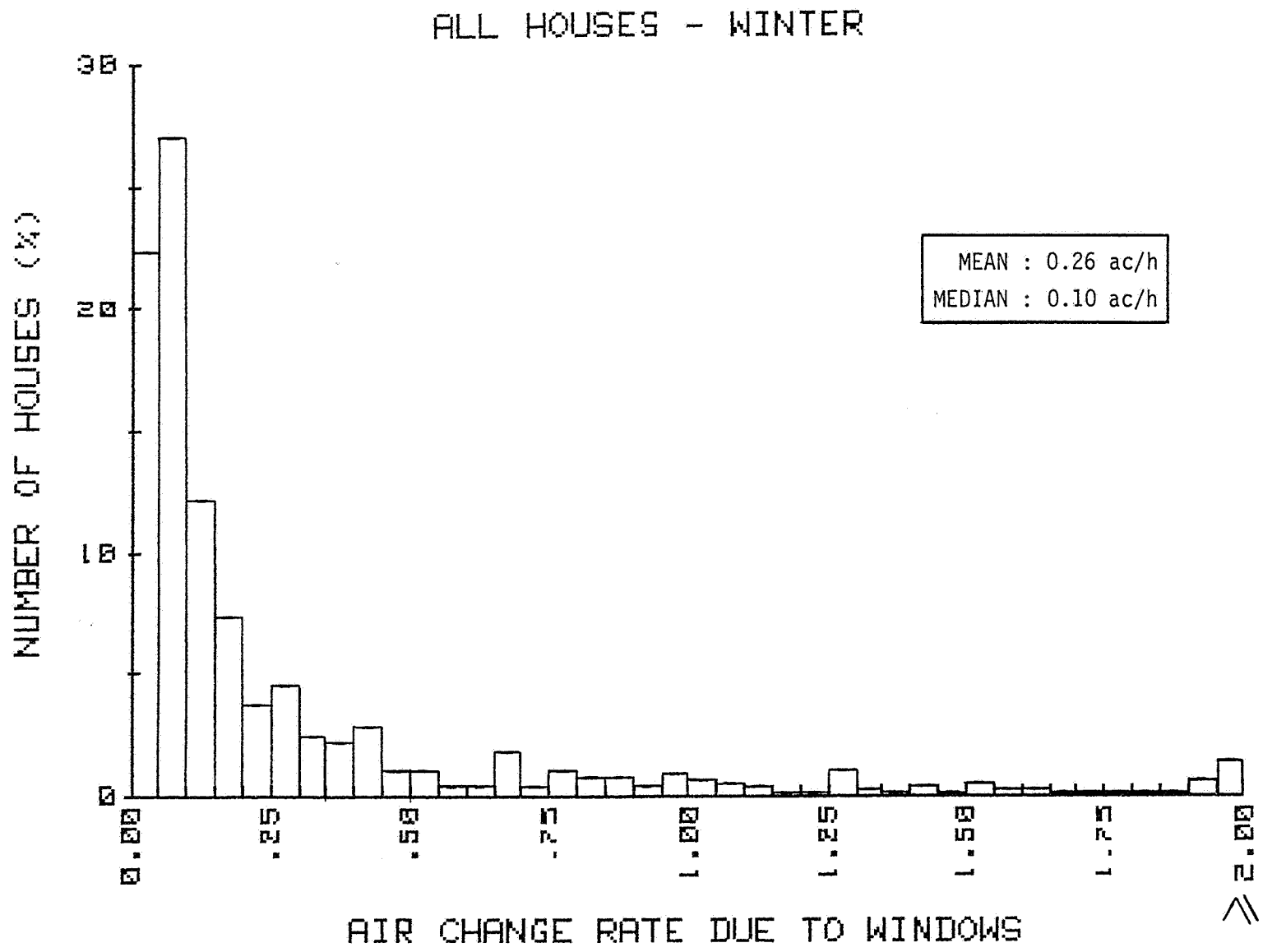

Fig. 1 : distribution of n_{occ} for dwellings and apartments (ac/h)

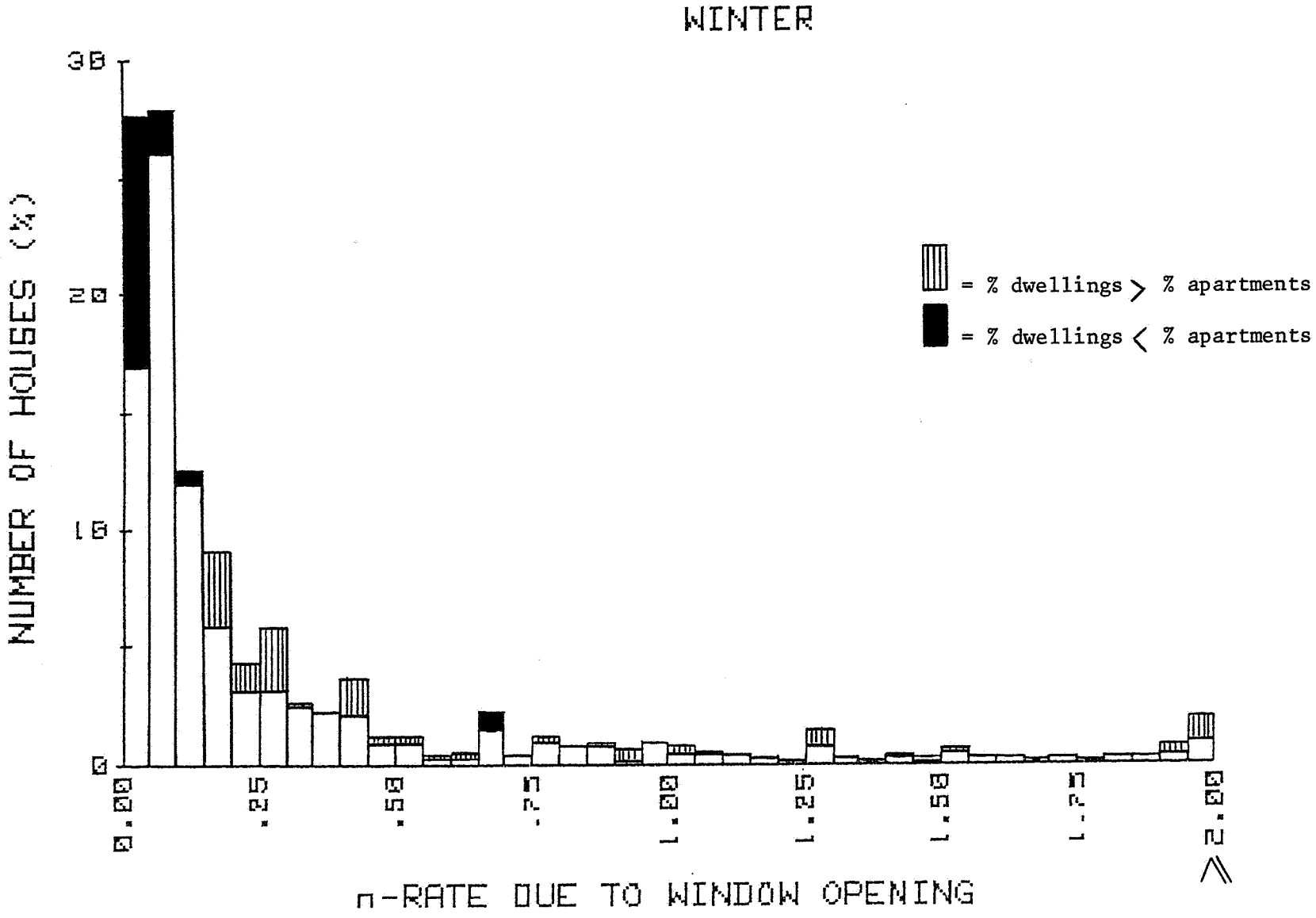

Fig. 2 : distribution of n_{occ}

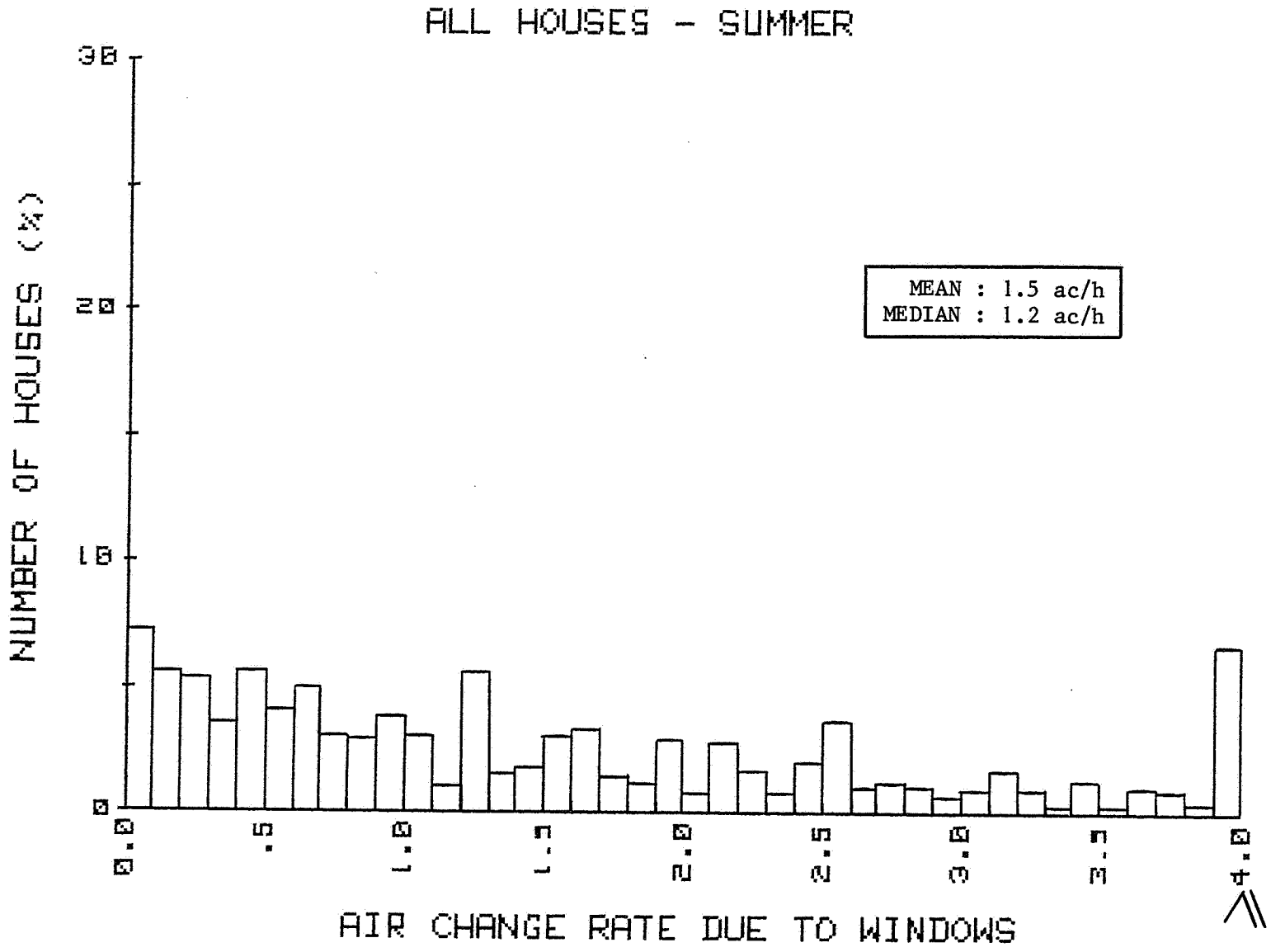

Fig. 3 : distribution of n_{occ} for dwellings and apartments (ac/h)