EFFECTIVE VENTILATION

9th AIVC Conference, Gent, Belgium
12-15 September, 1988

Paper 23

VENTILATION AND AIR QUALITY IN BELGIAN BUILDINGS: A STATE OF THE ART.

P. WOUTERS, D. L'HEUREUX, P. VOORDECKER AND
R. BOSSICARD

W.T.C.B./C.S.T.C.
Lombardstraat, 41
1000 Brussels
BELGIUM

1. Introduction

This paper tries to give a reasonable description of the state of the art of the Belgian building stock with regard to ventilation. It is a result of research sponsored by IWONL/IRSIA (Institute for scientific research in Industry and Agriculture), SPPS (Science Policy Programming), the Ministry of Economic Affairs and the Belgian Building Research Institute (WTCB/CSTC).

2. Airtightness of Belgian Buildings

The B.B.R.I. has carried out since the beginning of 1985 some 200 pressurisation measurements. This gives a rather good indication of the airtightness level of our building stock.

Two well prepared measurement campaigns of more or less randomly choosen buildings, each containing some 40...50 measurements give us interesting information. These are discussed in 2.1. and 2.2.

2.1. *Dwellings in the Namur' region* [1], [2]

Some 40 dwellings were measured in 1985 in the region of Namur as part of IEA Annex 8 "Human behaviour with regard to ventilation".
An overview of the airtightness results is given in fig. 1 :

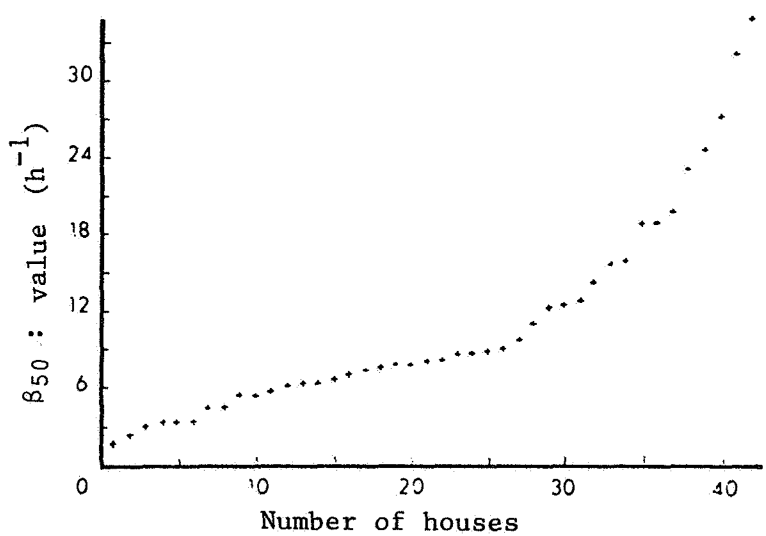


Fig. 1 : Overview of measured n_{50}-values in Namur [1]

These measurements, with an average n_{50}-value of 10 h^{-1} vary within a large range (3 - 40 h^{-1}). Enquiries carried out by the University of Namur (F.U.N.D.P.) [1] in these 40 dwellings have shown that there was on the one hand no relation between the impression by the inhabitants of the airtightness and the real airtightness and on the other hand - very suprisingly - there was for these 40 dwellings not a higher window use in more airtight dwellings, but instead in the more leaky dwellings.

2.2. *Airtightness measurement in Belgian school buildings* [3] [4]

The airtightness of some 45 school buildings was measured in the period 1986-1987. Fig. 2 gives the values found for the n_{50}-value as a function of the year of construction.

Three important conclusions from this study are :

- the measured airtightness vary over a very wide range : n_{50} from 0.5 h^{-1} to $\pm$ 40 h^{-1}.
  It is not so that the oldest buildings are the most leaky : there are a number of recently built school buildings which are extremely leaky. This is in most cases due to important leakages on roof level (see also 2.4.),

- only one of the measured school buildings had a mechanical ventilation system. All the other buildings can only be ventilated by opening the windows.

- the present airtightness level creates in a number of buildings problems : condensation and/or bad air quality in the airtight schools and draught problems and/or insufficient heating power for obtaining comfort temperatures in wintertime in other new well-insulated but leaky buildings.

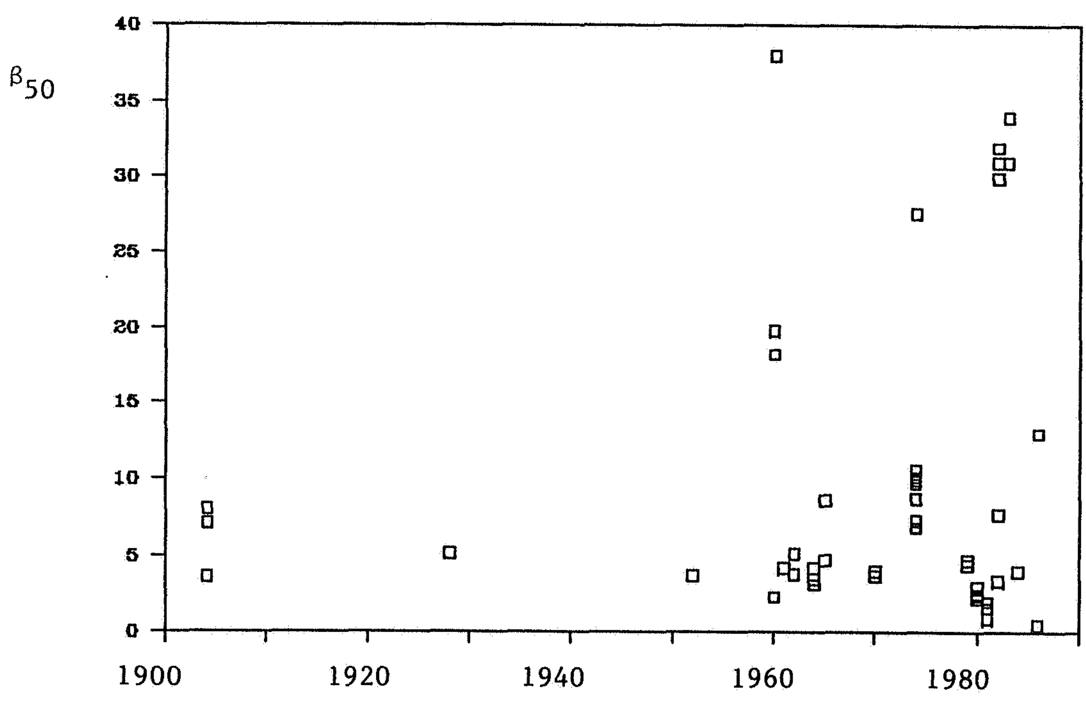


Fig. 2 : n_{50}-values for school buildings as a function of the year of construction [3].

These two important measurement campaigns in addition to a large number of individual measurements, have clearly showed that :

- the airtightness level of Belgian buildings varies over a very wide range (rough estimation of 95 % - region : n_{50} = 1 to 30 h^{-1})
- there is a very little concern about airtightness requirements with exception for windows but there is some growing interest.

It is clear that this situation is not optimal. In order to improve the present building quality, it is necessary to know where the major leakages are situated and their relative importance. This is analysed in 2.3. and 2.4.

2.3. *Windows and doors*

Windows and doors are by most people seen as major leakage sources in buildings but is this so in the reality ?
Fig. 3 shows the requirements [5] for new Belgian windows as well as the requirements in other countries.

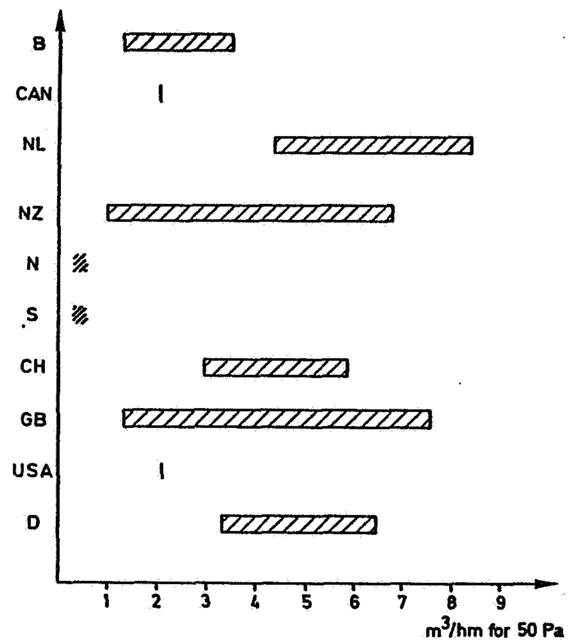


Fig. 3 : Airtightness requirements for new windows [5].

It indicates that the Belgian requirements are rather severe. A further analysis shows that windows with the Belgian airtightness requirements of fig. 3 have a small effect on the n_{50}-value : the n_{50}-value of a house with V = 300 m^3 and 50 m^3 of open joints in the windows will only increase with 0.6 h^{-1} which is a very small fraction of the average Belgian airtightness value of n_{50} = 10 h^{-1}.

Laboratory measurements at the B.B.R.I. on new windows [6] [18] (fig. 4) show that some 95 % of all the windows reach the lowest requirement and that even 20 % of the new window are 10 times more airtight than the strongest requirement.

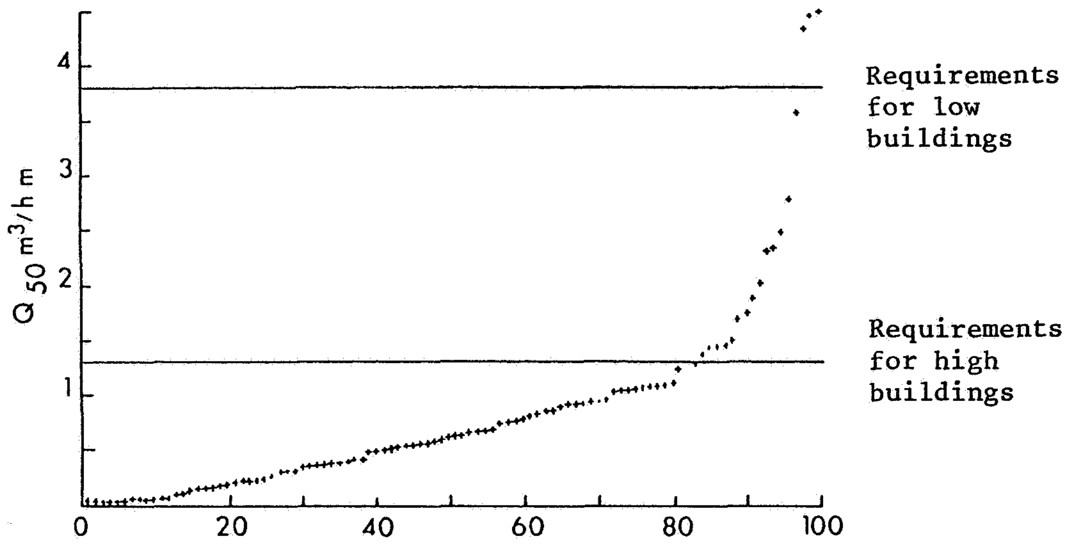


Fig. 4 : Comparison of a sample of 100 new windows with the Belgian airtightness requirements [6].

Measurements on site were also carried out but in a less systematical approach. These results can be summarized as follows :

- new windows reach in many cases the requirements of fig. 3 but higher values are found in some cases. This seems mainly due to a bad installation of the windows and/or a lower quality of manufacturing,
- older windows can be much leakier. In some cases values were measured in the range of 20 ... 40 m^3/hm. (at 50 Pa).
  Such windows represent in most cases the biggest air leakage of the building.

One can conclude by saying that windows and doors are in a certain part of the Belgian building stock, the major air leakage path but that they are in many Belgian buildings of minor importance.
This corresponds with the results reported in [5] where some 55 international measurements were analysed.
The average contribution of the window leakages is some 20 % (fig. 5).

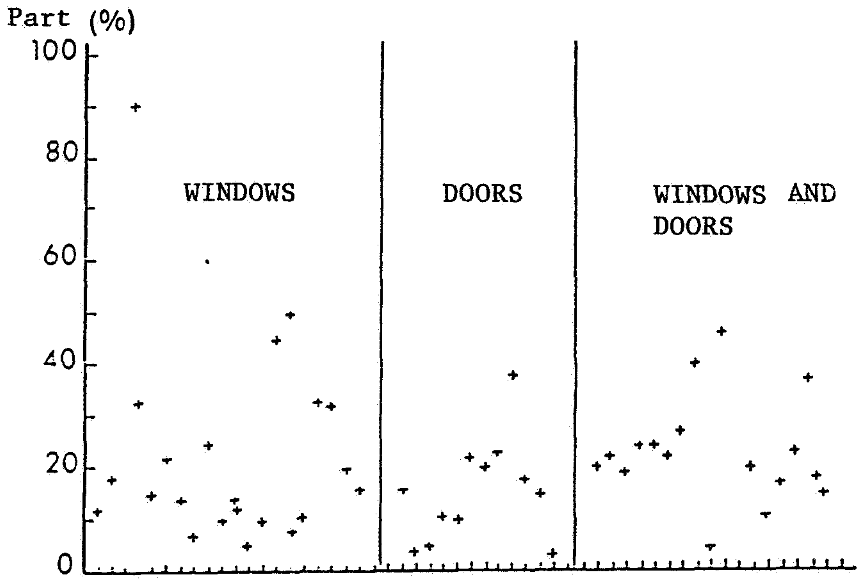


Fig. 5 : Leakages in windows an/or doors expressed as percentages of the total building leakage : results for some 55 measurement campaigns [5].

2.4. *Other leakages*

In many Belgian buildings there are important leakages besides the window leakages.

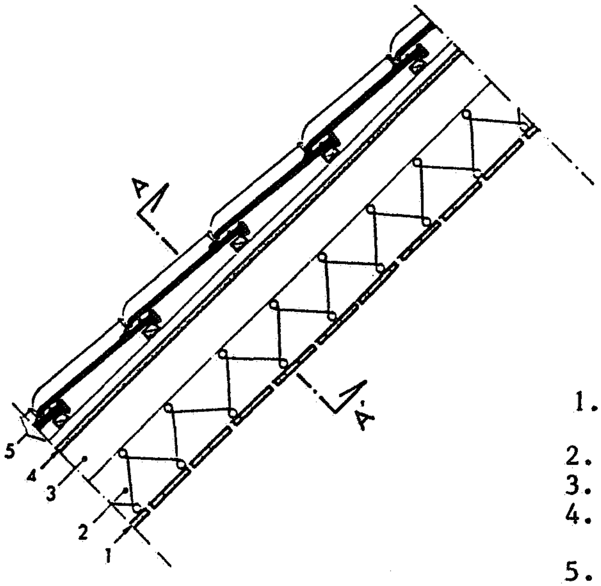
- inclined roofs can be very leaky if the interior finishing is made of wooden or aluminium panels with open joints and if there is no air-barrier in the roof.
  In 2 recently built school buildings, 1 office building and 1 individual dwelling, air flow rates of ± 100 $m^3/h,m^2$ were measured at 50 Pa difference.
  Fig. 6 gives a typical cross section of such a roof [7].

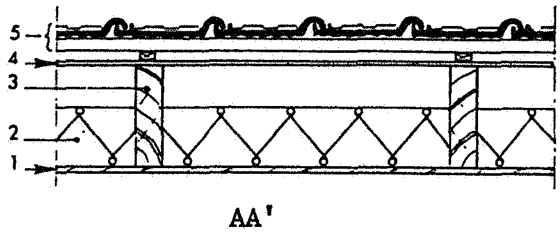
  In both schools and in the individual dwelling, 1 room has been renovated by installing a PVC-foil in the roof construction.

  Table 1 summarises the results. The results indicate the importance of good workmanship.

	n_{50} (h^{-1})
Situation as in fig. 6	27
PVC-foils (0.2 mm) between layers 1 and 2, joints not taped	12
PVC-foils (0.2 mm) between layers 1 and 2, joints well taped	5

Table 1 : Measured η_{50}-values in a classroom (with 3 different situations for the roof construction [7]





1. Interior finishing (small wooden or aluminium panels with open joints)
2. Mineral wool
3. Rafter
4. Menuiserite (cement plates reinforced with natural mineral fibers
5. undulated panel or tiles

Fig. 6 : Typical cross section of an inclined roof with very poor airtightness [7].

Lower air flow rates are found if the interior finishing is made of panels without open joints, but such finishing without an air-barrier elsewhere is not enough in order to obtain a good airtightness.

Very good results are always found if inclined roofs have an interior finishing made of gypsum board or similar panels without open joints and/or if the roof is plastered at its interior surface.
However, severe draught problems were found in a few cases with non-airtight light ornaments built in the roof construction.

- Cavity walls, which are very common in Belgium, are normally assumed to be airtight. Several measurements have shown that all types of walls which are plastered are very airtight (ϕ_{50} = air flow rate for $\Delta P = 50$ Pa is less than 1 m^3/hm^2). One type of cavity walls is rather leaky : cavity walls made of heavy concrete blocks without plastering have in most cases leakage rates of the order of $\phi_{50} = 10\ m^3/h,m^2$ [8] [9]. The two experimental houses at the BBRI (with $n_{50} \sim 10\ h^{-1}$) have such cavity walls. The walls represent 40 to 50 % of the total building leakage.

3. Ventilation previsions

A description of the ventilation previsions in an average Belgian dwelling and school building is very simple : most buildings have only openable windows to control (?) the ventilation. Small ventilation devices for air inlet, ventilation ducts and/or mechanical systems are seldom found.
This is probably largely due to the fact that until now clear recommandations and/or requirements don't exist. In highrise apartment buildings it is rather common to find natural ventilation ducts in the bathroom and the W.C. but nothing in the kitchen.

Most of the new Belgian houses have still no ventilation previsions. This is in strong contrast with the situation in surrounding countries such as the Netherlands and France.
Both countries have building regulations and the new buildings have therefore ventilation previsions. Table 2 summarises the situation in France for the year 1986 [10].

	Ventilation system		Apartments	Individual dwellings
Global and permanent ventilation	mechanical	traditional	70.000	100.000
		humidity controled	15.000	10.000
		supply + extract	5.000	5.000
	natural		10.000	40.000
Permanent ventilation	mechanical or natural		0	25.000
Total number of dwellings built in 1986			100.000	180.000

Table 2 : Estimation of the number of dwellings built in 1986 specified with regard to the ventilation system [10].

4. Ventilation related problems in Belgian buildings

4.1. Introduction

The combination of a large non-intended range of airtightness levels and the non-existence of appropriate ventilation previsions signifies in practice a very large variation in air change rates.
This is qualitatively shown in fig. 7.

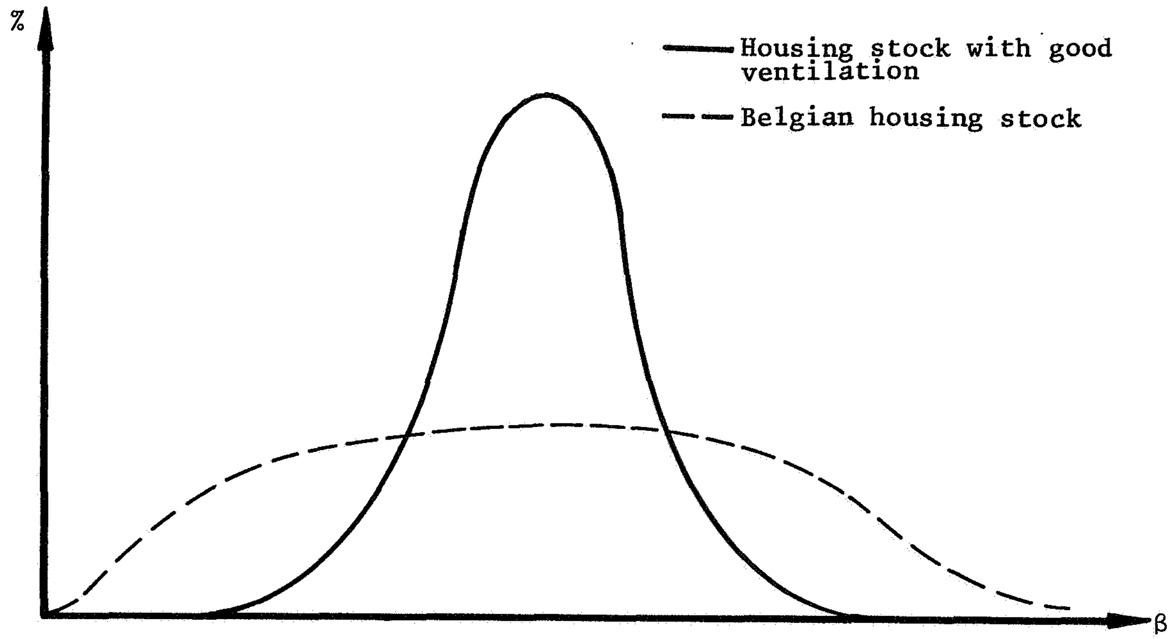


Fig. 7 : Seasonal air change rate for the whole building stock as a function of the ventilation system (qualitative approach).

Fig. 7 shows the average seasonal air change rate for the whole housing stock. In the situation with no ventilation previsions, there is a very wide range due to the wide range in airtightness and the non-existence of ventilation previsions.
It seems not possible to give clear statements about the average of both populations ($\bar{A} > \bar{B}$ or $\bar{B} > \bar{A}$) but it is very clear that the standard deviation of A is much smaller than the standard deviation of B.

One conclusion is that it is very difficult to predict the air change rate for dwellings with uncontrolled airtightness and no ventilation previsions (Belgian situation).

Fig. 8 gives the air change rates measured in an individual dwelling at the B.B.R.I. : too low air change rates during periods of low wind velocities and much too high air change rates during periods of high wind speed.

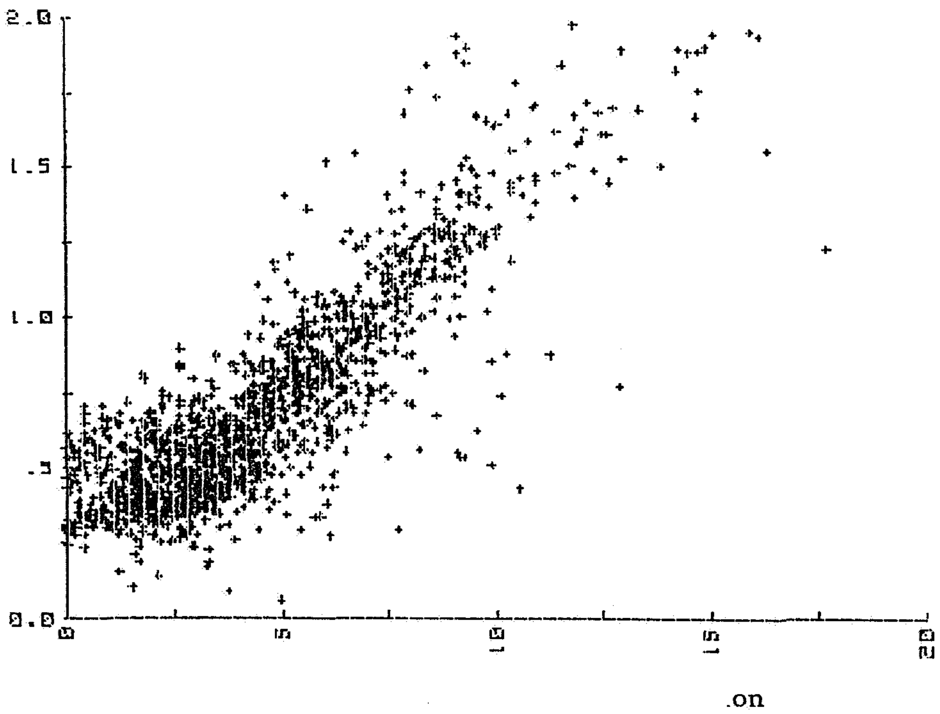


Fig. 8 : Measured hourly air change rates in an individual dwelling at the BBRI (period : December 1985 - March 1986, $n_{50} = 10\ h^{-1}$) [8]

The conclusion is that the level of air change rates in dwellings with an uncontrolled airtightness level and no ventilation previsions can vary over a very wide range. Very low air change rates will be found in airtight dwellings and/or during periods of low wind speeds and high outside temperatures and very high air change rates can be found in leaky dwellings and/or long periods of cold weather with high wind speeds.
A large range of problems can be the result of it. Some of them are discussed in 4.2. till 4.5.

4.2. Condensation and mould growth

Condensation and mould growth are a real problem in Belgium as well as in other surrounding countries. This problem is analysed in IEA-annex 14 "Energy and condensation". [11]
Fig. 9 shows the results of a large enquiry in some 2334 social dwellings distributed over 93 social housing estates [12].

Each point in the figure corresponds with 1 housing estate and it gives the average number of rooms per dwelling with condensation and/or mould growth on walls. This figure shows on the one hand that there are in most of the housing estates problems and on the other hand that the highest values are found in the more recently built housing estates.

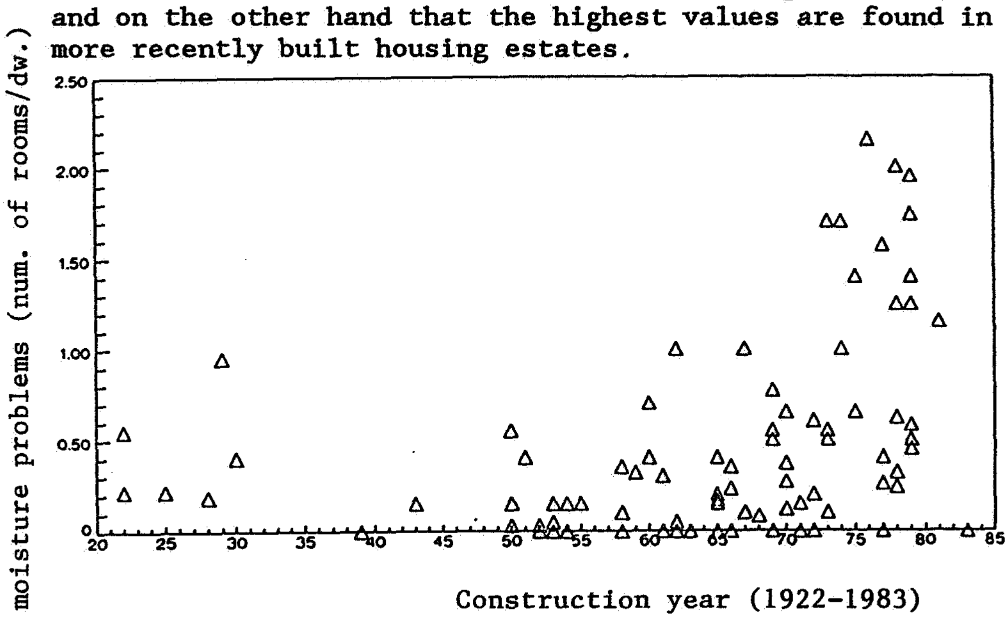


Fig. 9 : Average number of rooms per dwelling for 93 social housing estates as a function of the year of construction [12]

Condensation and mould growth are in most cases the result of a combination of the following conditions : thermal bridges, low internal temperatures, high humidity production per m^3 of dwelling volume and low ventilation rates. The BBRI has analysed in the period 1985-1988 a number of condensation and mould growth problems in depth. Pressurisation measurements were carried out and very low n_{50}-values in combination with no appropriate ventilation pressions were in almost all cases found. It is therefore our strong impression that on the one hand thermal bridges and/or a poor insulation level are the most evident reasons for these problems, but that on the other hand the ventilation condition can influence the condensation and mould growth problems in a strong way.

It is clear that very low ventilation rates have to be avoided. Fig. 10 shows ventilation rates measured in a recently high-standing built Belgian dwelling without any ventilation prevision. Such low air change rates in combination with a "normal" production of water vapour can give humidity levels which are high enough to create severe moisture and condensation problems. This is clearly illustrated in fig. 11, which gives the water vapour content of the air as function of the air change rate for a given situation and with the assumption of no condensation.

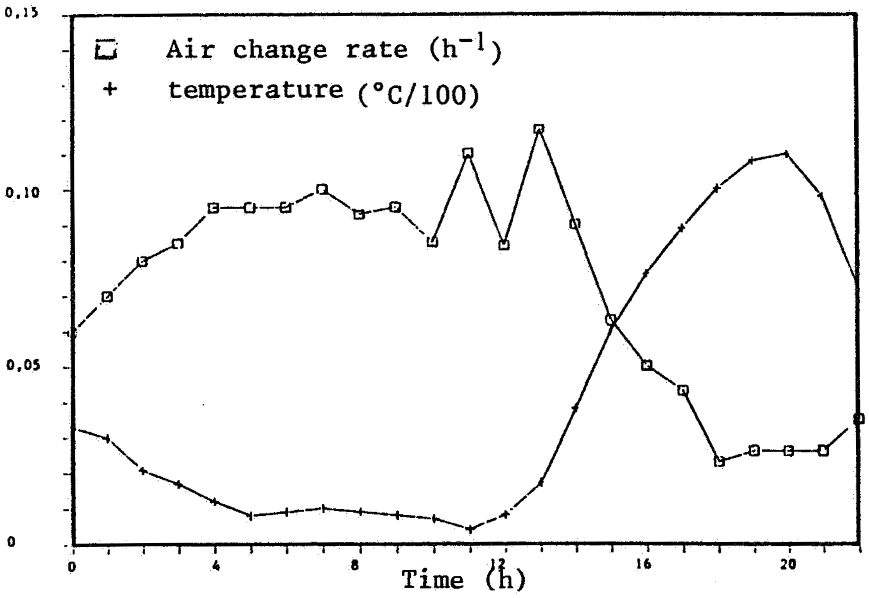


Fig. 10 :

Measured air change rate in a new individual dwelling [13]

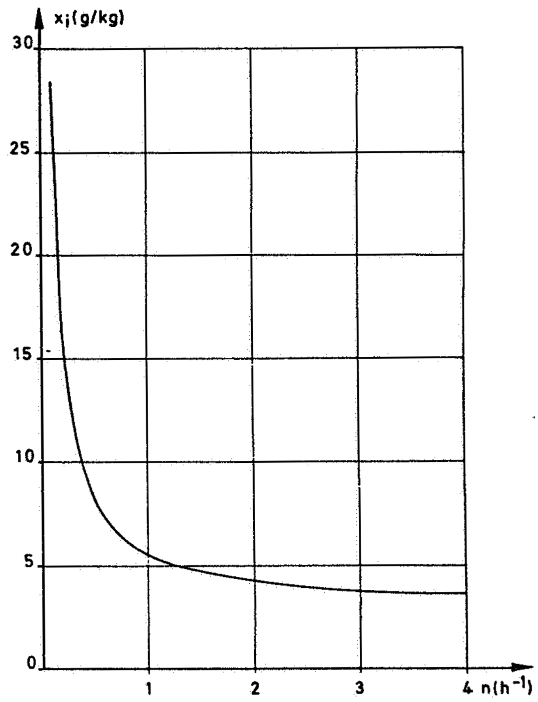


Fig. 11 : Exemple of the water vapour content as a function of the air change rate [14]

The fact that low air change rates have to be avoided does of course not mean that very high air change rates are the best solution. Very high air change rates in buildings with a high thermal intertia are in certain situations even the cause for humidity problems.

This is shown in a research project sponsored by IWONL/IRSIA. The following situation was simulated in a hot box - cold box : a room which was ventilated during a long period with open windows, so that the room becomes very cold, is from a certain moment on heated with the windows closed. Fig. 12 gives the cross section of the non-insulated cavity wall with balcony where fig. 13 gives the evolution of 3 representative temperatures.
The rise of the temperature in the corner A is ver slow.

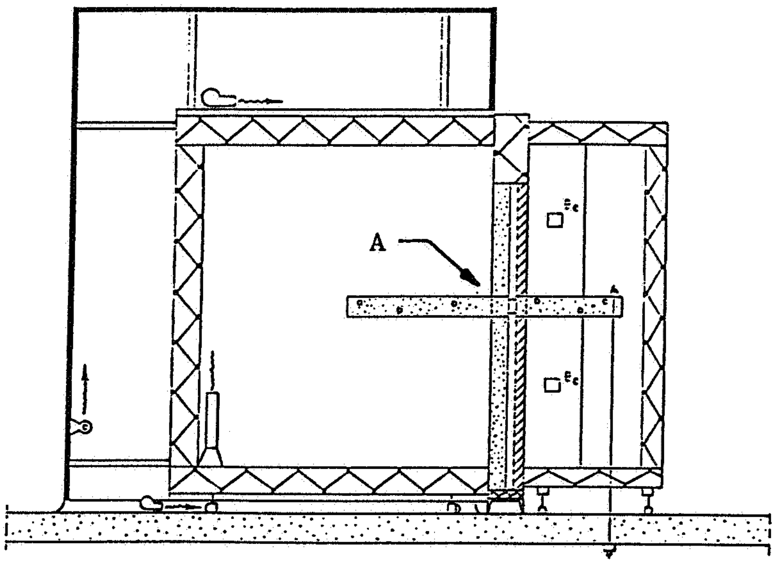


Fig. 12 : Cross section of hot box - cold box with cavity wall and balcony [15].

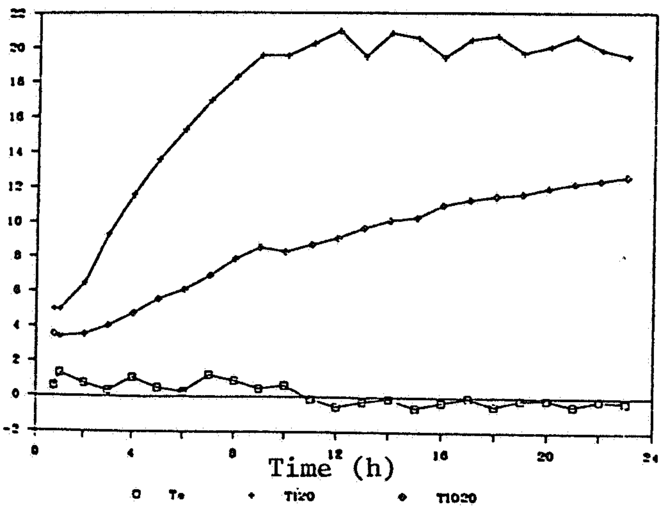


Fig. 13 :

Evolution of 3 representative temperature [15]

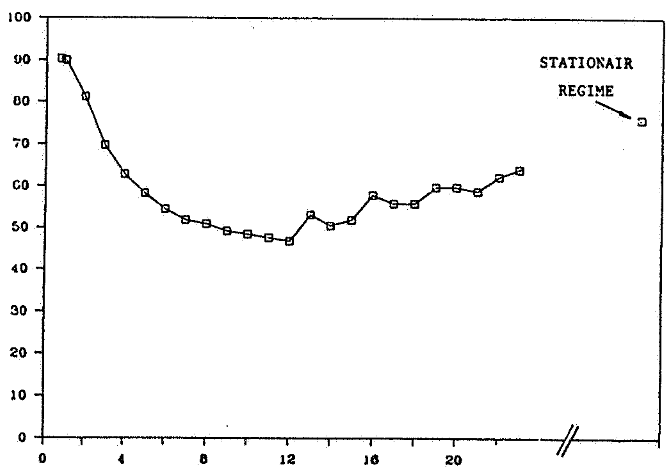


Fig. 14 :

Maximum allowable relative humidity above which condensation in A will occur [15].

This is also clear from fig. 14 where the evolution of the relative humidity of the indoor air is given above which condensation will occur in the corner A. The conclusion from this research is that it is much better to ventilate the room continuously with a rather low air change rate.

4.3. Air Quality - Odours

The air quality of the indoor air is in most cases proportional with the inverse of the air change rate.

Anoyance due to body odour is a problem in many classrooms and meeting rooms. A simple but rather accurate indication of the odour-level is the CO_2-level. Several countries have regulations based on acceptable CO_2-levels, which are situated between 1000 and 1500 ppm.

The BBRI has started in collaboration with the Superior Institute of Architecture "Sint Lucas" in Gent, and with the financial support of IWONL/IRSIA, a research with regard to air quality in schools. In the first phase 260 instantaneous CO_2-measurements were carried out in 10 different schools.

Fig. 16 summarizes the results. The average CO_2-level is 1702 ppm. Table 3 indicates the number of measurements exceeding a certain level. It appears that almost 50 % of the measured values were above 1500 ppm. A more detailed monitoring in 5 of these schools is foreseen during the heating season 1988-89.

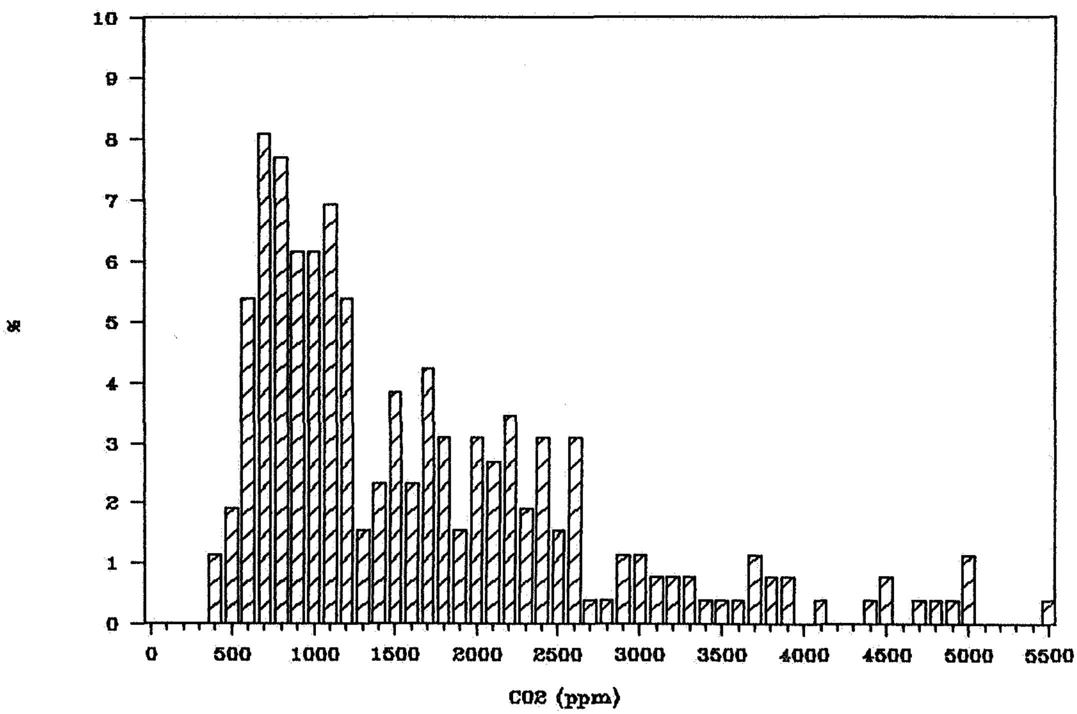


Fig. 16 : Histogram of measured CO_2-levels in 260 classrooms.

CO_2 (ppm)		≥ 1000	≥ 1200	≥ 1500	≥ 2000	≥ 2500	≥ 4000
Number	ABS	181	147	123	84	47	11
	%	70	57	47	32	19	4

Table 3 : Number of CO_2-measurements in classrooms exceeding a certain limit [16]

4.4. Radon

Research on the natural radio-activity in dwellings due to radon is carried out by the BBRI in collaboration with the Institute for Nuclear Research of the University of Gent and with the financial support of IWONL/IRSIA [17].

Long time concentration mesurements in 300 dwellings were done during the last 2 years. The research clearly indicates that the soil below the buildings is the major cause. Low levels are found above the rivers Samber and Meuse (average 39 Bq/m^3) while much higher values are found in the geological Ardennes (average 99 Bq/m^3).
Extrapolation of the measurement results lead to 65,000 Belgian dwellings which should be above 150 Bq/m^3. This level of 150 Bq/m^3 seems internationally accepted as the limit above which remedial actions become desirable.

It is clear that the radon-problem is much more than a ventilation problem. However, literature as well as a few Belgian experiences with remedial actions, indicate that ventilation research is on the one hand an important tool to understand the problem and on the other hand in many circumstances a big help to find efficient solutions.

4.5. Comfort problems

From several researches, carried out in the period 1985-1988, one can conclude that serious comfort problems are sometimes the results of poor airtightness, important localised leakages or - more in general - errors with regard to the airtightness.

The results of it are problems of a different nature :
- draught problems (mostly due to important localised leakages)
- high air velocity at inner door level.
- too low air temperatures (especially in very leaky, thermally well insulated buildings with a heating system dimensioned according the standards)
- difficulties to open inner doors due to high pressure differences across the doors (ex. 80 Pa difference was found between the kitchen and the living room in a recently built dwelling ($n_{50} \approx 12$ h^{-1}) when the extractor in the kitchen is functioning.

5. CONCLUSIONS

The Belgian research projects on ventilation in buildings, which were carried out during the last years, allow to give a rather precise overview of the quality of the Belgian building stock on this matter.

It shows that the airtightness vary very much from one building to another. Very leaky as well as very airtight buildings are frequently found. The almost non-existence of controlable ventilation previsions in individual Belgian dwellings is remarkable.

Some problems in Belgian Buildings (condensation, odours, radon, comfort) were discussed as well as their relation to ventilation. It is clear that a better ventilation will lead to a significant reduction of these problems.

An important conclusion with regard to the future concerns the urgent need of improved concepts for the ventilation control in Belgian buildings.

Finally, but not at least, it is our believe that the present situation of the Belgian building stock is not worser or better than 5 years ago. The difference is that we have now a reasonable idea where the problems are situated and that we have also already some answers how to solve them.

The Belgian membership of the Air Infiltration and ventilation Center has contributed in a significant way to this increase of knowlegde.

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