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Natural Ventilation in 18 Belgian Apartments: Final Results of Longterm Monitoring

P Wouters, B Geerinckx, D L'Heureux

Belgian Building Research Institute (WTCB/CSTC)
Violetstraat, 21-23, 1000 Brussels, Belgium

Synopsis

In the framework of a CEC demonstration project on humidity controlled ventilation, detailed measurements are carried out in 18 apartments in Namur, Belgium.

The paper gives a brief description of the building, of the airtightness of the apartments and of the ventilation provisions.

The largest part of the paper deals with the major outcomes of the study. This includes the following issues:
- *air flow rates: on the average, dependency of wind and temperature difference;*
- *indoor air quality indicators: CO_2 and water vapour;*
- *behaviour of the humidity controlled system;*
- *energy losses due to the ventilation.*

Finally, some conclusions about the ventilation performances and of the monitoring programme are given.

The demonstration project showed very well the influence of the building characteristics on the performances of the ventilation system.

1. Introduction

As part of a CEC demonstration project of DG XVII, the performances of a humidity controlled natural ventilation system, developed by the French firm Aereco, was studied in 3 buildings. These buildings were situated in Les Ulis (France), Schiedam (Netherlands) and Namur (Belgium). The following organizations participated in the project : Aereco, Electricité de France, CETIAT, TNO-BOUW and BBRI. General information as well as first results were reported in [1] , [2].
The final report of this project will be published in the autumn of 1993 [3].
This paper gives only information on the results found in the Namur building and with emphasis on the performances of the natural ventilation in general. More information can be found in [3].

2. The building

The building in Namur is situated in a suburban area of Namur. The test building makes part of a group of 4 similar buildings. Figure 1 shows the east facade. The construction is done between 1978 and 1982. The overall heat transmission coefficient of the facades is estimated to be 2.5 W/(m²K).
The building is divided into 2 piles consisting each of 9 apartments (level 0 till 8). 9 apartments are equipped with a natural humidity controlled ventilation system, the other 9 apartments are equipped with a standard natural ventilation system, called reference system. Figure 2 shows the floor plan of the apartments. The Shunt duct system has a single main duct for the levels 0 to 7. Level 8 has separate ducts. Figure 3 shows a cross section of the ducts.
The heating system is a central warm water radiator heating system. A gas fired boiler is in the basement. The annual energy consumption per dwelling for heating is 45x10³ MJ/year (1400 m³ gas per annum) based on the consumption of 1985. One apartment, the reference apartment at street level, was unoccupied during the whole duration of the measurement campaign.

To assure a good airtightness of the building, a rather detailed pressurization measurement campaign was carried out. The requirement was to achieve an airtightness of 3^{-h} at apartment level at 50 Pa pressure difference over the envelope. The measured results are summarized in table 1. The results are expressed with respect to the gross volume (external dimensions), which is 192 m³.

Apartment	Number	n_{50}					
		Average (h^{-1})	Minimum (h^{-1})	Maximum (h^{-1})	$\geq 2\ h^{-1}$	$\geq 2.5\ h^{-1}$	$\geq 3\ h^{-1}$
All	18	2.3	1.5	3.6	15	8	2
Hygro	9	2.1	1.5	3.6	7	3	1
Reference	9	2.5	1.8	3.0	8	5	1

Table 1: Summary of the pressurization measurements

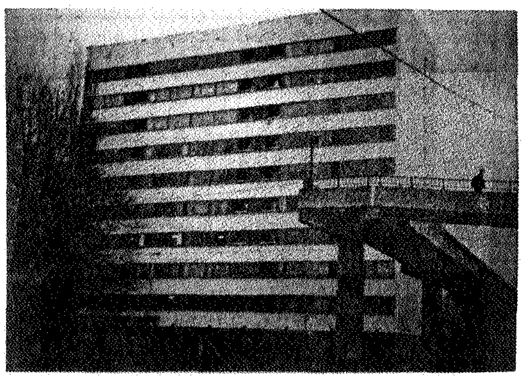

Figure 1: The East facade of the Namur building

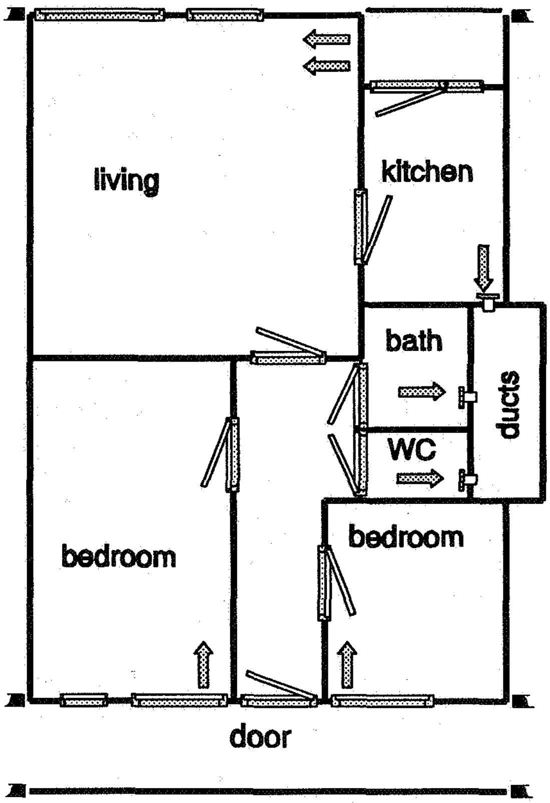

Figure 2: The floor plan of an apartment

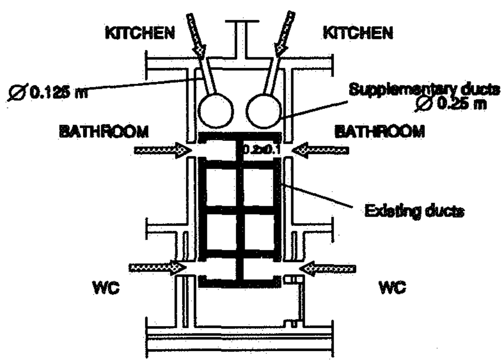

Figure 3: Cross section of the extraction ducts

3. The measurements

By use of the MATE (= Multi Purpose Automated Tracer Gas Equipment) system [3],[4], the air flow rates, CO_2- and H_2O-concentrations and flow rates were measured with respect to the extraction ducts in kitchen, bathroom and toilet. Also the air temperatures in these rooms were measured. All variables were measured each 20...25 minutes. Two different periods were used for the analysis :

- Campaign 1: 17-02-1990 till 16-03-1990 (28 days)
- Campaign 2: 28-11-1990 till 03-01-1991 (37 days)

4. Results

4.1. Air flow rates

The average air flow rates for the total duration of both measurement campaigns are given in table 2 as function of the level and the type of ventilation system. The average air flow rate for the occupied apartments is 83 m³/h. The distribution of the total extracted air flow rates for all reference and humidity controlled apartments is presented in figure 4. From these results, the classification of the air change rates as given in table 3 can be made. As given in table 3, the air flow rate is almost never below 0.25 h^{-1}.

	Total air flow rates (m³/h)								
	0	1	2	3	4	5	6	7	8
Refer.	185	116	121	108	78	88	98	63	83
Hygro	71	91	106	108	119	93	77	82	92

Table 2: ***Average air flow rates for the whole dwelling, reference and humidity controlled apartments, Namur***

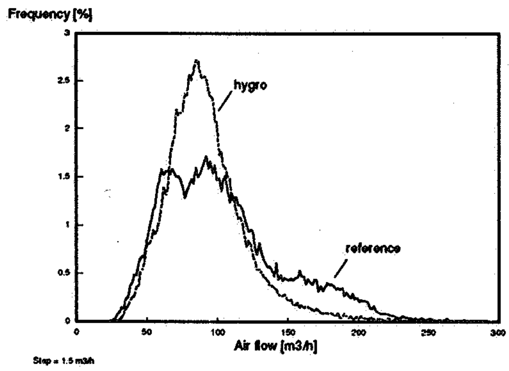

Figure 4: ***Histogram of air flow rates for total dwelling in the Namur building***

Air change rate (h^{-1})	% of time		% of time accumulated	
	Ref.	Hygro	Ref.	Hygro
0-0.1	0.0	0.0	0	0
0.1 - 0.25	1.9	0.9	2	1
0.25 - 0.50	32	36	34	37
0.50 - 0.75	38	50	72	87
0.75 - 1.00	15	10	87	97
1.00 - 1.50	12	2.9	99	100
> 1.50	0.7	0.1	100	100

Table 3: ***Distribution of the total air change rates for apartments in Namur***

The effect of wind speed and temperature on the total air change rate is illustrated for 2 apartments: one unoccupied apartment at street level in which the natural supply and extraction openings were the whole time open (figure 5) and an occupied apartment at the 7th floor (figure 6). For the unoccupied reference apartment at street level, a clear dependency of wind speed and temperature difference can be observed. The strange trend for large temperature differences may be misleading given the small amount of measurements. For the occupied apartment, the wind effect is significant but not as strong. The temperature effect is marginal. This can be explained by the small stack effect.

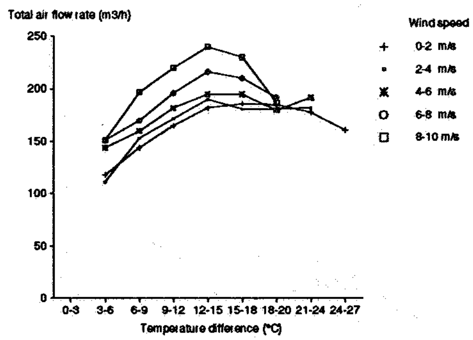

Figure 5: ***Variation of the total air flow in the unoccupied apartment***

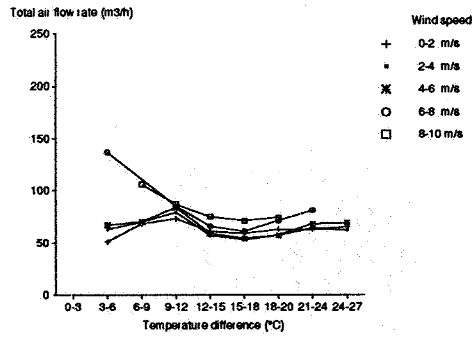

Figure 6: ***Variation of the total air flow rate in the reference apartment at level 7***

4.2. CO_2-concentrations and CO_2-rates

The average CO_2-concentrations are given in table 4. The distribution of the CO_2-concentration is given in figure 7. The average concentrations in kitchen, bathroom and toilet are not so high. Unfortunately, no information is available for the living room and the bedrooms.

	Apartment level and average CO_2-level (ppm)								
	0	1	2	3	4	5	6	7	8
Refer.	351(*)	670	850	870	970	890	1420	1160	650
Hygro	580	740	820	780	700	870	890	810	700

Table 4:. ***Average CO_2 concentrations (ppm) for the whole dwelling, reference and humidity controlled apartments, Namur***
(*)= nearly outside concentration, the average measured increase was 1 ppm

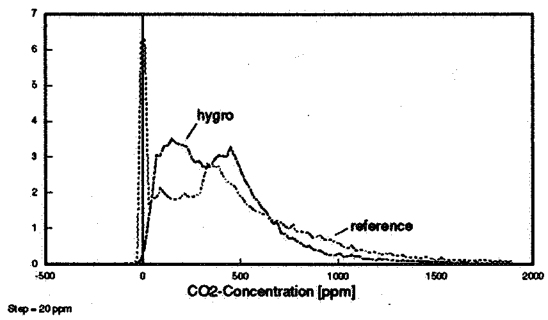

Figure 7: ***Histogram of CO2-concentrations (with reference to outside)***

The extracted CO_2-flow rates as well as the distribution over the different ventilation ducts are presented in figure 8. The average value for the occupied apartments is about 43 l/hour. It must be stressed that only the extraction through the ducts is taken into account. In figure 9, the extracted CO_2-rates are expressed as function of the temperature difference for wind speeds between 0 and 2 m/s. There is some increase as function of the temperature difference. Two explanations can be given :

- for small temperatures, there are probably open windows and cross ventilation;
- gas cooking will increase the temperature in the kitchen and can also explain the higher CO_2-rates for larger temperature differences.

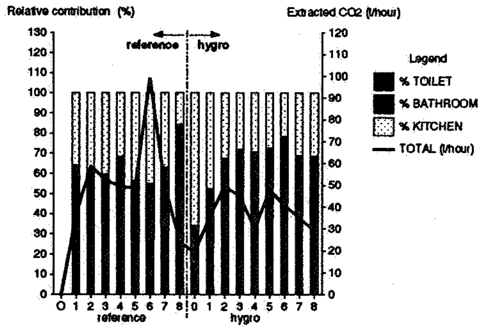

Figure 8: ***Distribution of the CO_2-flow rates***

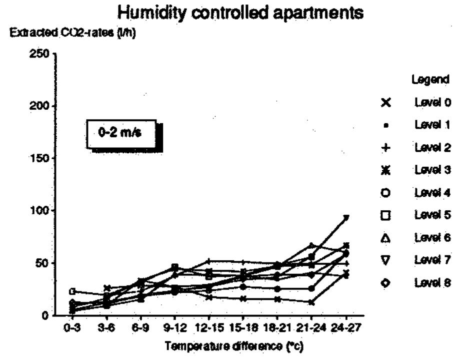

Figure 9: ***Variation of the extracted CO_2-flow rates***

4.3. Water vapour

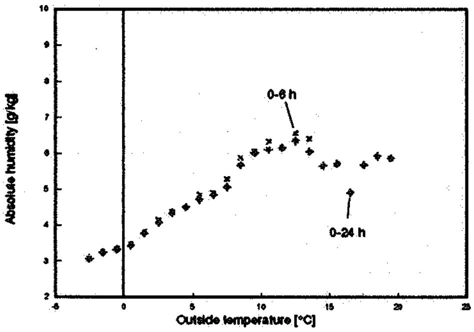

Figure 10: ***Average absolute humidity as function of the external temperature***

Figure 10 shows the average outside absolute humidity as function of the outside temperature. For temperatures in the range of -5 to 10 °C, there is almost a linear dependency.

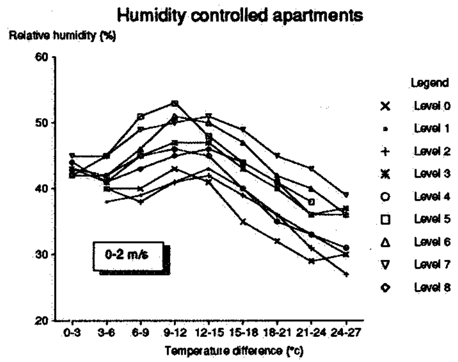

Figure 11: ***Variation of the average relative humidity***

The measured relative humidities in the apartments range between 37 and 48 %. The variation of the relative humidity in the reference apartments as function of the temperature difference is shown in figure 11. The lower values for larger temperature differences are mainly due to the lower absolute humidity outside for lower temperatures. Lower values are also found for temperature differences close to zero. This can probably be explained by open windows.

The air temperature is on the average high in these apartments : the averages for the individual apartments range from 20 to 24 °C. (measured at the height of the extraction ducts).

The extracted water vapour rates through the ventilation ducts as well as the distribution over the 3 ducts is presented in figure 12. The average value is 5.0 kg/day. This value is rather low compared with values commonly used in literature. However, a very similar value was found in the ELIB study [5]. Figure 13 shows the measured distribution together with the values measured in Namur.

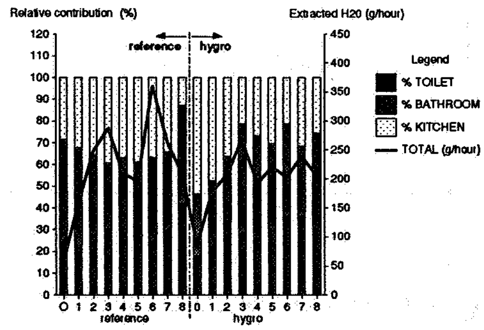

Figure 12: ***Total extracted H_2O and relative contribution of different ducts***

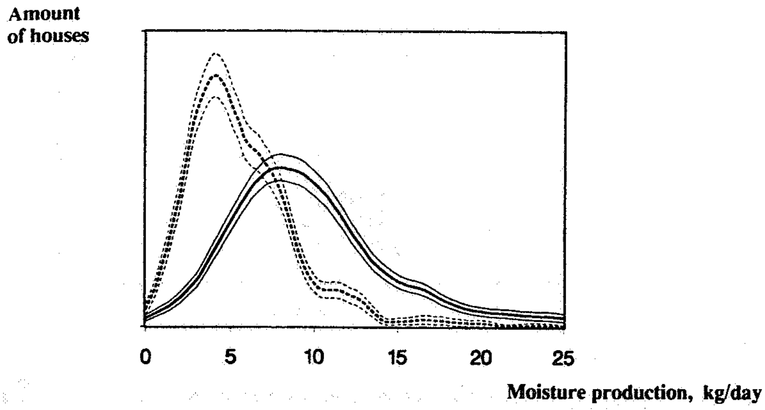

Figure 13: ***Density functions and 67% confidence intervals of moisture production in single-family and multi family (---) houses***

4.4. Relation between extracted water vapour and extracted CO_2

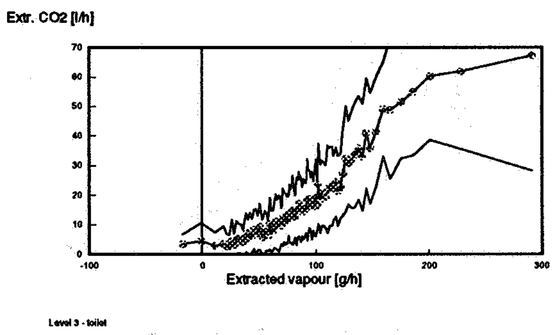

Figure 14: ***Extracted CO_2 versus extracted water vapour***

CO_2 and water vapour are 2 important indicators of air pollution. Is there a good correlation between them? Figure 14 shows the correlation between these 2 variables as well as the standard deviation. On the average, there is a very good correlation, but the 67% confidence band indicate that there is a large spread on the individual results.

4.5. Variation of air flow rate as function of the relative humidity

The technology used in the grills aim to vary the cross section as function of the relative humidity. Does the air flow rate also change as function of the relative humidity?

As an example, figures 15 and 16 give the variation of air flow rate as function of the relative humidity for the 2 kitchens at the 3rd floor. In the case of the humidity controlled apartment, there is a clear increase as function of the relative humidity, whereas in the case of the reference apartment, the inverse trend is observed. Table 5 shows the situations where a clear difference between the trends in the reference and humidity controlled apartments is found (indicated by 'Y'). In the majority of the cases, the humidity controlled grills clearly modify the relation air flow rate versus relative humidity.

	0	1	2	3	4	5	6	7	8
Toilet	-	Y	-	Y	-	Y	Y	-	-
Bathroom	-	Y	Y	Y	Y?	-	-	-	Y
Kitchen	Y	Y	Y	Y	Y	-	Y	-	Y?

Table 5: ***Comparison between the reference and humidity controlled apartments with respect to the extracted air flow as function of the relative humidity, Namur***

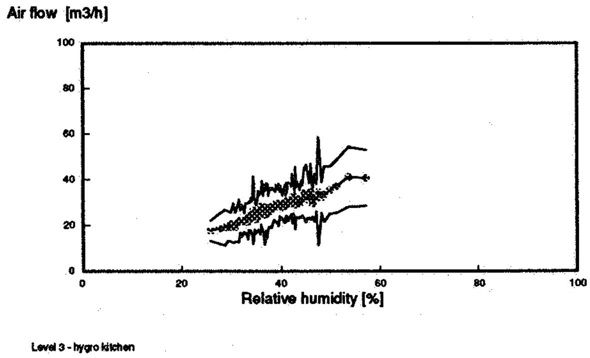

Figure 15: ***Air flow rate versus relative humidity***

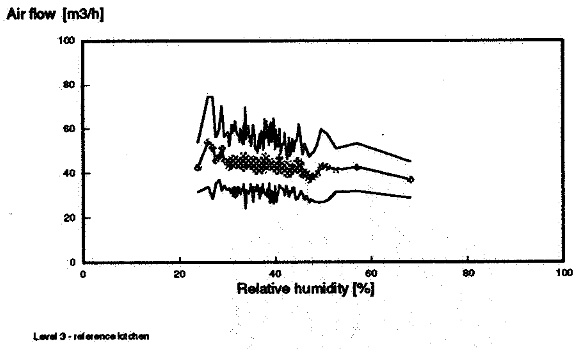

Figure 16: ***Air flow rate versus relative humidity***

4.6. Energy related results

The distribution of the energy losses at apartment level due to the ventilation is presented in figure 17. The self-regulating effect of the humidity controlled grilles is significant.

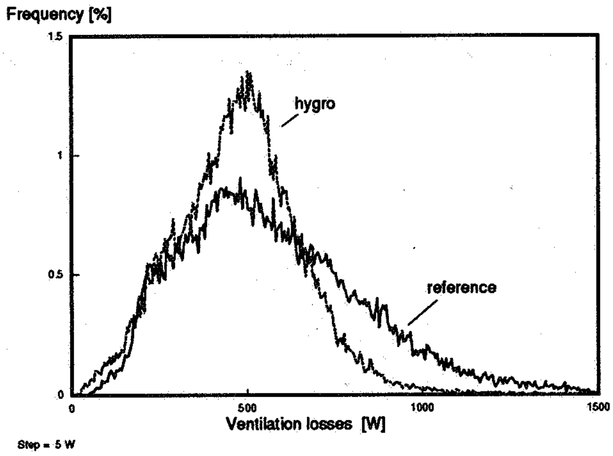

Figure 17: ***Histogram of energy losses due to ventilation***

5. Conclusions

In the framework of this report, only general conclusions are given :

- the average total air change rate for the 17 occupied apartments in Namur is around 83 m³/h or O.5 h^{-1} (expressed with respect to the air volume). The air flow rate varies between 63 and 121 m³/h;
- it was possible to determine the effect of wind speed and temperature on the total air flow rate;
- the average CO_2-concentration in the occupied apartments is of the order of 845 ppm. However, a very large variation is observed : between 580 and 1420 ppm on the averages;
- the average extracted CO_2-rates through the ducts is of the order of 43 l/hour at apartment level. Very large variations are observed as well as a certain relation with the number of occupants;
- the average value for the extracted water vapour is of the order of 5 kg/day. This is less than often found in literature but very similar with the values found in the Swedish ELIB study;
- on the average, a very good correlation is found between extracted water vapour and extracted CO_2-rates. For the individual points, rather large variations are found;
- in the majority of the cases, the humidity control function of the ventilation grills significantly influence the air flow rate as function of the relative humidity;
- because of the humidity control function also the energy losses due to the ventilation are reduced.

With respect to the influence of the humidity controlled ventilation grills, much more information can be found in the final report of this project [3]. As indicated in this report, the building characteristics in combination with the duct characteristics have a major impact on the performances of the system. Due to this, rather poor results are found for the Schiedam building, moderate results for the Namur building and good results for the Les Ulis building.

As a general conclusion, this study has on the one hand resulted in very interesting information with respect to the performances of natural ventilation systems in apartments. On the other hand, it has clearly highlights the relation between building characteristics and ventilation performances.

6. Acknowledgments

The authors wish to thank DG XVII of the Commission of the European Community for supporting this project. We are also very greatfull to the occupants of the dwellings involved in the study as well as the social housing society responsible for the building. Finally but not at least, we would like to thank the other participants in the project.

7. References

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