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Efficiency Measurements of Kitchen Hoods.

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Synopsis

Air extraction in the kitchen is an essential element in all ventilation strategies for dwellings. This can be done by natural ventilation or mechanical extraction. In practice, the use of mechanical kitchen hoods is very common in Belgium.

As part of a research carried out for the Belgian IWONL/IRSIA, the laboratory for Hygrothermics and Indoor Climate of BBRI carried out measurements to evaluate the efficiency of kitchen hoods.

The test procedure applied at BBRI is a mix-up of two existing standards. The major difference between the two standards is the use of an interference device to simulate occupants behaviour. Just this interference device seems to have a crucial influence on the collection efficiency of a kitchen hood.

Besides the determination of the collection efficiency, a definition is given of a pollution index. This index evaluates the pollution level in the room when using a kitchen hood.

Also a method is explained to design and to evaluate a kitchen hood installation taking into account air flow characteristics and collection efficiencies.

List of Symbols

E : Collection efficiency index
P_i : Pollution index
C : Measured concentration of tracer gas [ppm]
q : Tracer gas injection rate [m^3/h]
Q : Extraction air flow rate [m^3/h]
V : Volume of test chamber [m^3]
t : Time [h]

1. Efficiency measurements

1.1. Introduction

The main function of a kitchen hood is to extract the pollution from cooking. Standards NF E 51-704 and SS433 05 01 describe a method to measure the collection efficiency of a kitchen hood. Based on both standards BBRI constructed in 1991 a test chamber for such kind of evaluations. For a technical description of the test chamber and the method, a reference is made to [1] and [2].

The produced pollution during a cooking process is simulated by a tracer gas. A known quantity is injected in a saucepan at a hot plate while the kitchen hood is working. After stopping the kitchen hood and the injection of tracer gas, the remaining concentration of tracer gas is measured in the test chamber. The collection efficiency index is determined based on this measured concentration.

Figure 1 shows the BBRI test chamber.

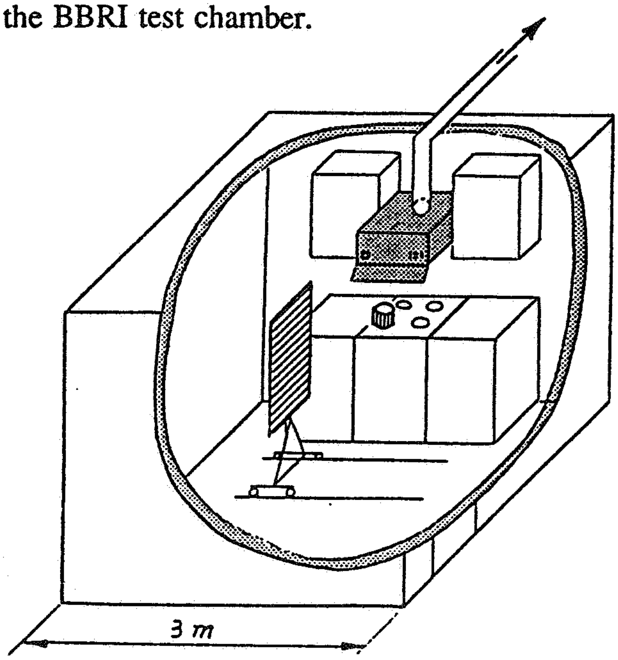

Figure 1 : Schematic view of the BBRI test chamber

1.2. Evaluation indices

Both above mentioned standards express the collection efficiency using the following formula:

$$E = 1 - \frac{C.10^{-6}}{\frac{q}{Q}\left(1 - e^{-\frac{Q}{V}.t}\right)}$$

The expression in the denominator of this equation is the concentration which should be found in case of perfect mixing, using the same injection and air flow rate as during the test. Perfect mixing means that the tracer gas is completely mixed with the room air before extraction. An efficiency of 0.00 is found if the concentration inside the test chamber is the same as in the case of perfect mixing.
An efficiency of 80 % may be interpreted that 20 % of the pollution is coming into the kitchen before being extracted. The collection efficiency index expresses the effectiveness of the catching of pollutants by a kitchen hood.

A drawback of the definition of the collection efficiency is that no information is obtained about the resulting pollution in the kitchen. The collection efficiency is calculated comparing a measured concentration and a concentration in case of perfect mixing for the same air flow rate.

The effect of the air flow rate on the pollution in the occupied zone is eliminated. The collection efficiency index focuses on the indoor air quality for a given air flow and is an energy related performance index.

It would be interesting to define another index which gives more information about the air quality in the occupied zone. Therefore, "the pollution index P_i" is defined at BBRI.

The pollution index P_i is defined as the relative concentration in the occupied zone for a certain kitchen hood at a certain air flow by taking the situation of 100 m^3/h extraction with perfect mixing as a reference. This reference situation corresponds with a pollution index 1.00 .

This corresponds with the following formula :

$$P_i = \frac{C.10^{-6}}{\frac{q}{100}(1-e^{-\frac{100}{V}.t})}$$

The pollution index focusses more on the indoor air quality level in the room and is a quality performance index. One can probably come to other performance indices.

2. Results

2.1. Results

For the moment, as well Belgian as Dutch kitchen hoods have been tested.

All kitchen hoods are installed at a height of 650 mm above the level of the hot plate and tested at different air flows.

Figure 3 to 4 illustrate the above defined performance indices of the tested hoods as function of the extraction air flows. Besides the results obtained for the kitchen hoods, the figures also give results of the performances of a ventilation grill. This is a ceiling extraction grill, mounted at the ceiling in the left corner of the test room at 50 cm from the rear and side wall. As expected the performances of this ceiling grille are much lower than for the kitchen hoods.

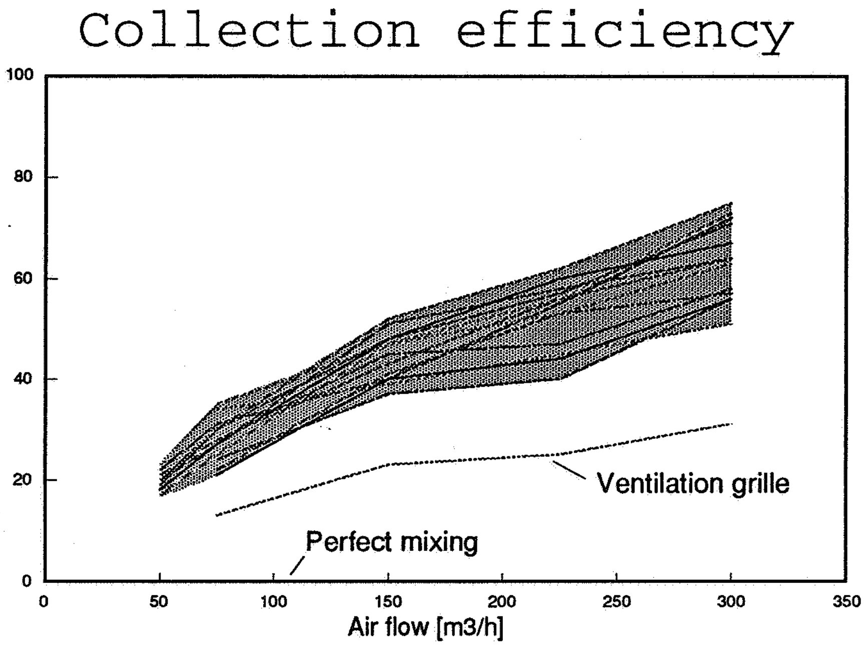

***Figure 2 :** Collection efficiency indices.*

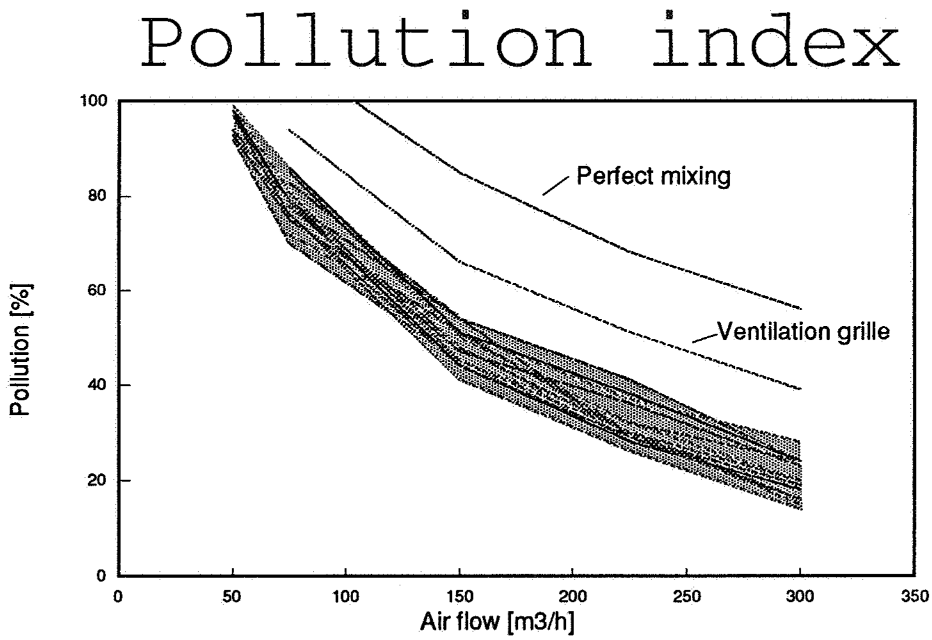

***Figure 3 :** Pollution indices.*

2.2. Interpretation

1) It is clear that the collection efficiency increases (and the pollution index decreases) as the air flow increases. Therefore, it is not possible to give one collection efficiency index for an extraction device. It is an air flow related index.

2) Above figures shows that the behaviour of the efficiency index as function of the air flow is rather unpredictable. The curves of all hoods have different shapes. This can also be an indication of a rather large measurement error.

3) The collection efficiency of an air extraction device is related to the air flow as well with the shape as with the distance between the pollution and the extraction device. When using an air extraction grille with a low air flow (eg. 25 m^3/h in a toilet as mentioned in the Belgian standard NBN D 50-001), the assumption of perfect mixing seems to be realistic. When using such a device with an important air flow (> 150 m^3/h), the efficiency increases a lot and the assumption of perfect mixing is not longer valid.

4) The pollution index gives more information about the pollution level in the space. The pollution index decreases more then the efficiency index increases as function of the air flow. This can be explained by the difference in definition between the two indices. Even by an efficiency of 0.0, a certain amount of pollution is evacuated.
The calculated pollution indices also illustrate that all kitchen hoods evacuate more efficient by 50 m^3/h than in case of perfect mixing and 100 m^3/h. This is an important remark with respect to energy consumption.

5) All tests are carried out using the interference device. As will be explained in §3.3. this interference device has an not neglectible influence on the determination of the collection efficiency index.

6) The kitchen hoods have other performances than the extraction grille with respect to efficiency. Table 1 and 2 give an overview of the most important results. A reference is made to figure 2 and 3.

	Collection efficiency indices				
	Perfect mixing	Tested kitchen hoods			Ceiling grille
Air flow		MIN	AVG	MAX	
50	0	17	20	23	-
75	0	21	28	35	13
150	0	37	44	52	23
225	0	40	53	62	25
300	0	51	64	75	31

***Table 1 :** Summary of collection efficiency indices.*

Air flow	Pollution indices				
	Perfect mixing	Tested kitchen hoods			Ceiling grille
		MIN	AVG	MAX	
50	119	92	96	99	-
75	109	70	78	86	94
150	85	41	48	54	66
225	68	26	32	41	51
300	56	14	20	28	39

Table 2 : Summary of pollution indices.

7) One must remember that the test procedure at BBRI is not conform with the French or Swedish standard but a mix up of both standards. The test procedure, especially the starting up of the experiment, seems to be more logical than the one described in both standards.

3. Sensitivity analyses

3.1. Repeatability of tests

As also mentioned above, the results are rather unpredictable. This can include a rather large uncertainty in the measurements. Table 3 represents the results of 4 measurements on the same installation evacuating an air flow of 300 m^3/h.

Test nr.	Collection efficiency [%]
1	72
2	72
3	73
4	71

Table 3 : Repeatability of efficiency tests

From these first results, one can conclude that the measurements are reliable. But due to the low number of comparative tests, following 95% confidence interval is obtained for the efficiency: $\hat{E} = 72 \pm 2.6$ [%]

3.2. Influence of height of installation of the hood

The influence of the height of the kitchen hood above the cooking plate doesn't seem to be neglectible. The following table gives the results of a kitchen hood installed at different heights. The test is done using an extraction device installed in a hood (width: 0.6 m, depth: 0.55 m, height: 0.08 m). The mentioned height of installation is the distance between the hot plate and the hood.

Figure 4 illustrates the effect of the placing of the kitchen hood on the collection efficiency.

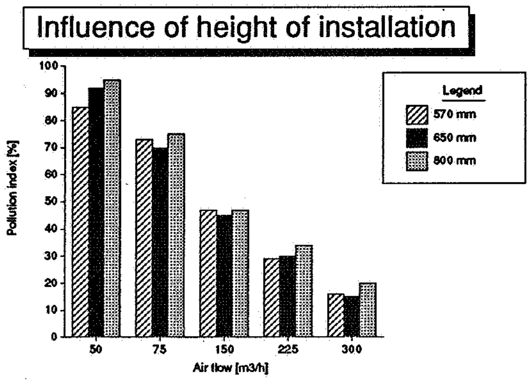

***Figure 4 :* Influence of installation height**

For the investigated height of this kitchen hood, the height has little effect on the pollution in the kitchen. The influence of the air flow on the pollution is much bigger. This conclusion can only be taken for the tested configuration : the hood installed between cupboards and a wall behind it. The influence of the height can be more important in other configurations e.g. cooking isles and if cross ventilation occurs in the kitchen.

3.3. Influence of interference device

As also reported in [2], the interference device has a non neglectible influence on the extraction performances of a kitchen hood. This is in contradiction with the results reported in [5]. As mentioned in the Swedish Standard SS433 05 01 (May 81) a wooden plate (height: 1m, width: 0.5 m) is used to simulate the occupants behaviour. The interference device is moving from one side wall to another with a speed of 0.5 m/s and a frequency of 0.125 Hz. The purpose of the interference device is to simulate occupants behaviour.

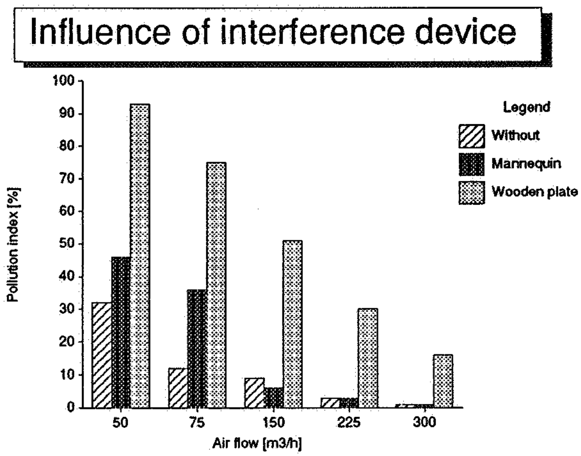

***Figure 5 :* Influence of interference device**

Figure 5 illustrates the performances of a kitchen hood without interference device, with a wooden plate as interference device and a non-dressed female mannequin as device. The interference device has a crucial influence on the pollution in the kitchen. The most important difference between above mentioned standards is the use of the interference device. With respect to standardisation, the choice of this interference device seems to be important.

4. Evaluation and dimensioning of a kitchen hood installation.

The main purpose of a kitchen hood is to evacuate pollution during cooking. The capability to perform this job depends mainly on :
- the extracted air flow
- the collection efficiency of the kitchen hood.

Figure 6 illustrates a procedure to design a kitchen hood installation and to evaluate its performances taking into account both above mentioned parameters.

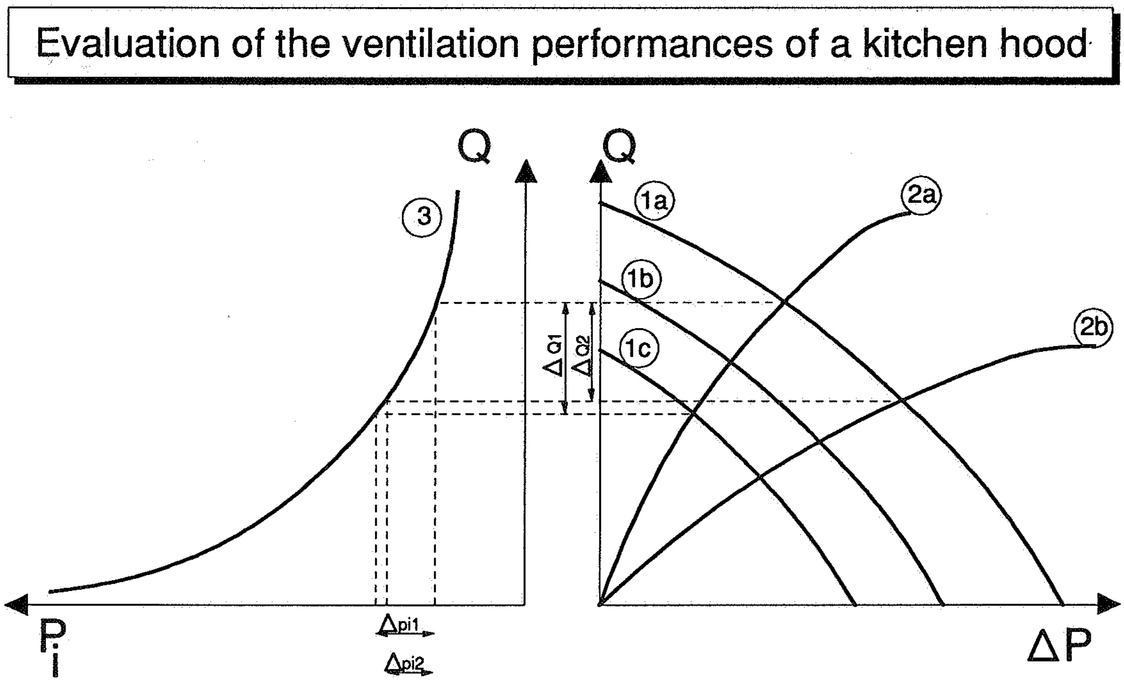

Figure 6 : Evaluation of the ventilation performances of a kitchen hood

The six curves on the figure are :

1a) relation 'pressure difference across kitchen hood-air flow rate' for a kitchen hood and operating in stand max.

1b) relation 'pressure difference across kitchen hood-air flow rate' for a kitchen hood and operating in stand medium.

1c) relation 'pressure difference across kitchen hood-air flow rate' for a kitchen hood and operating in stand minimum.

2a) relation 'pressure difference across ductwork-air flow through ducts' for a certain ductwork.

2b) relation 'pressure difference across ductwork-air flow through ducts' for a another possible ductwork.

3) relation 'air flow rate-kitchen hood pollution index' corresponding to the kitchen hood of curve 1 to 3.

Curves 1x) can be provided by the manufacturers of kitchen hoods, curves 2x) can be calculated when the flow characteristics of the used ducts are known. Curve 3 can be one general curve (see figure 3) representing the pollution index for kitchen hoods.

Some examples :

1) ΔQ_1 at the figure gives an idea of the difference in air flow rate that will be extracted by the kitchen hood connected to a ductwork if different stands (max <-> min) will be used.
2) Δp_{i1} gives an idea of the difference in pollution index obtained by the same kitchen hood connected at a ductwork but using different stands.
3) ΔQ_2 gives an idea of the difference in extracted air flow rate by a kitchen hood operating in the same stand but connected at different ductworks.
4) Δp_{i2} illustrates the difference in pollution index obtained by a kitchen hood operating in the same stand but connected to different ductworks.

Above graphs allow to design an appropriate ductwork for a certain kitchen hood, to evaluate its evacuation performances and to investigate the performance differences using different fan speeds.

Remark :

Above approximations don't take into account the pressure drop in the kitchen due to airtightness. But this does not influence the idea behind this manner of designing and evaluating because the effect of airtightness can be included in the curve expressing the pressure drop in the ductwork. Therefore the philosophy remains the same.

4. Conclusions

1) Instead of only defining the collection efficiency index it seems to be interesting to define another performance index, more specific the pollution index, to evaluate the air quality performances of an extraction device.

2) As proven in previous experiments the interference device has a big influence in the determination of the performance indices. Therefore, it is important to link the obtained results with the interference device.

3) One must remember that the test procedure at BBRI is not conform with the French or Swedish standard but a mix up of both standards. The test procedure, especially the starting up of the experiment, seems to be more logical then the one described in both standards.

4) When air flow characteristics are known of the used apparatus and also collection efficiencies, a theoretical evaluation of the system can be done.

5. Acknowledgements

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Many thanks to all, especially to Didier L'Heureux and Richard Bossicard who prepared the experiments and built the required equipment.

6. References

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