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# PERCEIVED AIR QUALITY: SHOULD WE USE A LINEAR OR A NON-LINEAR SCALE FOR THE RELATION BETWEEN ODOUR INTENSITY AND CONCENTRATION ?

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## ABSTRACT

Assessing the perceived air quality in decipols by trained panels can be performed rather perfectly today. To calculate the olf load from these results is a little more problematic as one requires olf loads which can simply be added (linearly). The reason for this difficulty is the nonlinear relation between the perceived air quality in decipol and the pollution load in olf. The relation can be expressed by an exponential function in a range between 1 to 15 decipols. Unfortunately the exponent and the constant in the exponential function differ for different substances. For the most substances they can fairly well be approached by a root law.

This is shown for three very different examples: the required outdoor air flow for ventilated rooms with different outdoor air qualities, the exponential law for linoleum and the balance of pollution of a rotary heat exchanger.

## KEYWORDS

Air quality, Contamination sources, Measuring technique, Perceived air quality

## INTRODUCTION

Almost ten years ago Fanger proposed to assess perceived indoor air quality by sniffing panels and introduced two new units: the olf and the decipol. The method has been used widely and very succesfully. It is till today and will likely be the only method to quantify perceived indoor air quality in future. Unfortunately the air pollution load in olf cannot be measured directly but has to be assessed indirectly by a trained panel. The trained panel can only give results for the intensity in decipol or in a percentage of dissatisfied persons, convertible into decipol, which again is to be converted into olfs.

The members of a trained panel learn the decipol scale by comparison with fixed 2-propanone concentrations. There is no problem as far as the perceived indoor air quality in decipol or the percentage of dissatisfied persons in a given space have to be estimated.

As soon as the pollution load in olf is to be calculated from the perceived indoor air quality in decipol a problem arises if the relation between odour intensity and concentration is different from the 2-propanone-decipol relation. That this will certainly happen can be explained by fig. 1 (ASHRAE). The odour intensities can be expressed as an exponential function of the concentration for various substances. For different substances they differ in their absolute values as well as in their exponents.

Similar results have also been found by Knudsen et al (1997). They found a linear relation of the percentage of dissatisfied (PD) to a relative concentration of a substance in a log-probability diagram. Every substance can be characterized by two coefficients. But to calculate an olf load according to equ. 1 requires in my opnion a linear relation between the two concentrations which does not always exist or one gets pollution loads which cannot simply be added.

The exponents of many substances are smaller than 1, frequently in a range of 0.3 to 0.7. Acetone or 2-propanone has a rather high exponent as shown in fig. 1. If the majority of the other substances has a smaller exponent, it seems very likely that a nonlinear calculation method for converting decipol into olf values and for adding and subtracting is a better approach. Measuring results especially for the pollution by air-conditioning components become more obvious by using a square root rule.

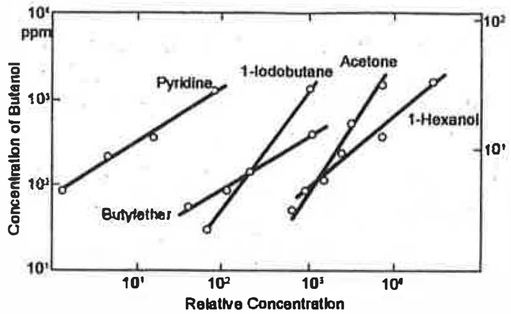


Fig. 1 Odour intensities as a function of concentration.

The pollution load in olf has to be estimated to enable air-conditioning engineers to calculate pollution loads of buildings and air-conditioning systems. This is a very important task of the future work. And we should as quickly as possible find a proposal how to calculate pollution loads from perceived air quality values.

## METHODS

Some examples of pollution assessments from experiments in our institute and some given in the literature will be calculated by a linear and a nonlinear calculation method to show that a nonlinear relation gives a better and relatively good agreement.

By definition one olf is the pollution by one average person (Fanger 1988). And also by definition one achieves a perceived indoor air quality of one decipol when 10 l/s of clean air are contaminated with one olf. Accordingly two olfs will be yielded by two average persons. Will two olfs spoiling 10 l/s of air result in a perceived air quality (PAQ) of two decipol, particularly if they are originating from any sources?

Is the perceived air quality scale linear to the pollution in this case? If the perceived air quality vs. concentration of the pollution by men has the same exponent as 2-propanone this is very likely for this special case. The relation between the concentration of 2-propanone and decipol is nearly linear as shown in fig. 2 (Bluyssen 1991). The idea to calibrate a panel by a linear scale would solve many problems of non linear perception. Unfortunately this would only work correctly if the relation between PAQ and concentration is very similar for all substances.

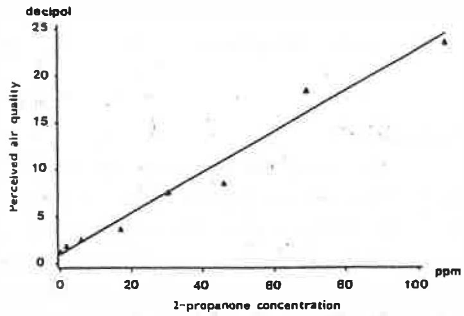


Fig. 2 Calibration curve: decipol vs. 2-propanone concentration

There is some doubt that this can be assumed. As mentioned earlier fig. 1 is giving a comparison of the odour intensity of several substances versus concentration. The exponents of the relations are differing for different substances. Unfortunately acetone or 2-propanone has a relatively high exponent. The advantage of 2-propanone is that it has a similar exponent as the pollution by persons.

The equations given for the pollution by persons show a linear relation between the perceived air quality in dp, the number of persons (olfs) polluting the air and the inverse air flow rate (Equ. 1).

$$\dot{V} = 10 \frac{G}{(c_i - c_a)\varepsilon_v} \qquad (1)$$

$\dot{V}$ air flow rate
$G$ source strength of pollutant in olf
$c_i$ perceived indoor air quality in decipol
$c_a$ perceived outdoor air quality in decipol
$\varepsilon_v$ ventilation efficiency (here $\varepsilon_v = 1$)

The perceived air qualities must be linearly connected with each other to be able to use equ. 1.

If one differentiates between different sources of pollution (index r room, p person, rlt air conditioning system) the expression changes to equation (2).

$$\dot{V} = 10\left\{\frac{G_r + G_p}{(c_i - c_a)\varepsilon_v} + \frac{G_{rlt}}{c_i - c_a}\right\} \qquad (2)$$

For many substances the relation between source strength $c_s$ and perceived air quality $c_m$ is not linear. The next better approach seems to be a square root relation (Finke 1996) with a constant $K_m$ for every substance

$$c_m = K_m\,(c_s)^{0,5} \qquad (3)$$

This relation has to be used for the source strength as well as for the perceived air quality. Combining equ. (3) and (1),(2) results in the new equ. (4) and (5).

Equ. 1 would then turn to

$$\dot{V} = 10\frac{G}{(c_i^2 - c_a^2)^{0,5}\,\varepsilon_v} \qquad (4)$$

and equation 2 to

$$\dot{V} = 10\left\{\frac{G_r^2 + G_p^2}{(c_i^2 - c_a^2)\varepsilon_v} + \frac{G_{rlt}^2}{c_i^2 - c_a^2}\right\}^{0,5} \qquad (5)$$

**RESULTS**

Three different examples will be calculated.

1. Required outdoor air flow in a low and in a highly polluted environment

According to equation (1) and similar equations in the standards (DIN 1946 Teil 2; CEN/TC156 WG6) the air exchange rates of buildings with highly polluted outdoor air have to be much higher than in low polluted environments.

To achieve an indoor air quality of 4 dp in rooms located in different environments assuming an outdoor air quality at one place of 1 dp and of 3 dp at the other place the air flow rate has to be increased by a factor of 3 according to equ. (1) or (2) for the place with the lower outdoor air quality. Using the non linear relation equ. (5) results in a required air exchange increase of 1,4. Fig. 3. shows the required air flow rates for indoor air qualities (IAQ= RLQ) of 2, 4 and 6 dp for various outdoor air qualities (Finke 1996). The source strengths of the different pollution sources $G$ are assumed to be constant in this example. The rather high air flow rates (□) for low outdoor air quality are not in agreement with our experiences.

Calculated with the nonlinear relation (equ. 5) the air flow rate (Δ) is nearly independent of the outdoor air quality as long as both values are not too close together.

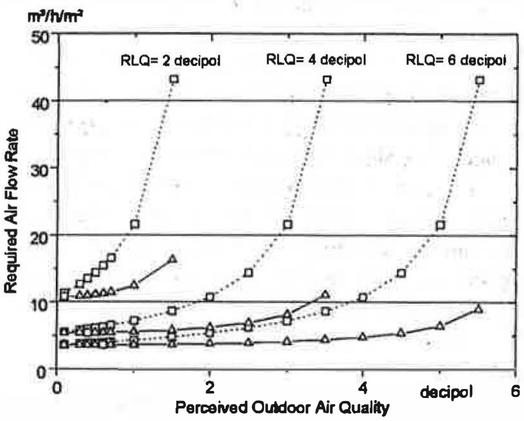


Fig. 3 Air exchange rate to achieve 2, 4 and 6 dp for various out door air quality levels

The curves (Δ) resulting from the nonlinear calculation in fig. 3 show a much better agreement to our experience.

2. Fig. 4 shows the perceived air quality $c_m$ in dp versus the area $A_m$ of a linoleum sample which is assumed to be proportional to the concentration of the pollution. The perceived air quality can be approximated best by

$$c_m = 26,4\,(A_m)^{0,36} \qquad (6)$$

An approximation by an exponent of 0.5 is not much worse and much better than 1. Equ. 6 can be approximated very well in the given range by

$$c_m = 50.8\,(A_m)^{0,5} \qquad (7)$$

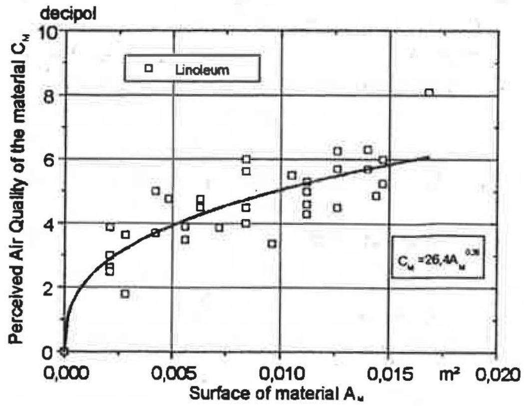


Fig. 4: Perceived air quality $c_m$ versus the surface $A_m$ of a linoleum sample

3. As a third example measuring results of Peijtersen (1994) shall be used. He measured the pollution of supply air by the extract air in a rotary heat recovery device.

Fig. 5 shows one of the typical results. The reduction of the decipol values of the extract air passing the wheel seems to be lower than the pollution of the outdoor air. The experiments have been performed with two rotary velocities ( 2 and 10 rpm).

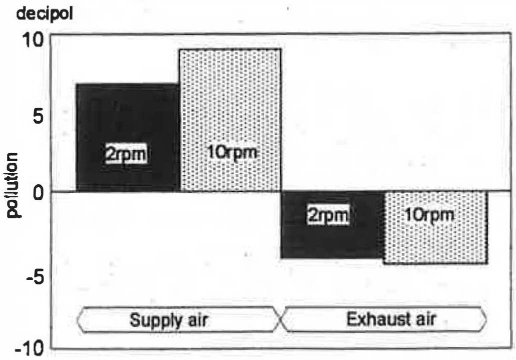


Fig. 5: Difference of the pollution of the supply and exhaust air passing a rotary heat regainer

The entrance and the exit pollution loads before and after the rotary heat exchanger are also given by Peijtersen. In table 1 his results are repeated and the results of a linear (a) and a non linear calculation (b) of the pollution load balance are shown. They are evaluated by the following equation derived from equ. 2 and 5:

$$a = \frac{c_{sa} - c_{sb}}{c_{eb} - c_{ea}} \tag{8}$$

$c$ = perceived air quality in dp
Indices:

- $s$ supply air
- $e$ exhaust air
- $b$ before rotor
- $a$ after rotor

$$b = \sqrt{\frac{c_{sa}^{2} - c_{sb}^{2}}{c_{eb}^{2} - c_{ea}^{2}}} \tag{9}$$

If the pollution of the supply air is mainly originating from the exhaust air continuity reasons require a result smaller or close to 1. Table 1 and fig. 6 show the results. The results of the non linear calculation are much closer to 1 than of the linear.

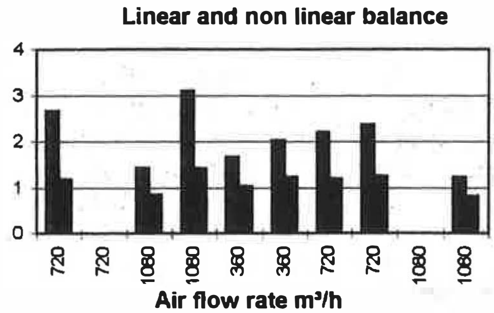


Fig. 6: Relation of the pollution difference in the supply and exhaust air of a rotary heat exchanger by linear ($a$, left column) and square root ($b$) calculation (right column)

## DISCUSSION

The relation between the perceived air quality in dp and the source strength in olf for different substances can be described by an exponential function. The constant and the exponent of the function differ for any substance. 2-propanone used for calibration of trained panels has a high exponent, nearly double as high as for the most polluting materials. Therefore it seems to be appropriate to use an exponent of 0.5 for the relation between perceived air quality and pollution load. Especially the results of Peijtersen concerning the heat regainer can much better be explained than with his linear evaluation.

Table 1 Pollution balances across the rotary heat exchanger by equ. 8 (a) and 9 (b)

Indices: *s* supply air, *e* exhaust air, *b* before rotor, *a* after rotor

| Air flow | Rot. | sb | sa | eb | ea | **a** | **b** |
|---|---|---|---|---|---|---|---|
| $m^3/h$ | rpm | dp | dp | dp | dp | - | - |
| 360 | 10 | 1.8 | 10.5 | 12.8 | 6.5 | **1.4** | **0.9** |
| 720 | 2 | 1.3 | 8.5 | 10.7 | 8.0 | **2.7** | **1.2** |
| 720 | 10 | 0.8 | 3.8 | 7.5 | 8.9 | **<0** | **<0** |
| 1080 | 2 | 1.7 | 4.7 | 7.3 | 5.2 | **1.4** | **0.9** |
| 1080 | 10 | 3.0 | 6.1 | 7.5 | 6.5 | **3.1** | **1.4** |
| 360 | 2 | 1.6 | 8.6 | 10.1 | 5.9 | **1.7** | **1.0** |
| 360 | 10 | 1.5 | 10.8 | 10.5 | 5.9 | **2.0** | **1.2** |
| 720 | 2 | 2.4 | 5.7 | 7.0 | 5.5 | **2.2** | **1.2** |
| 720 | 10 | 2.0 | 8.4 | 9.2 | 6.5 | **2.4** | **1.3** |
| 1080 | 2 | 2.8 | 5.8 | 6.0 | 6.1 | **<0** | **<0** |
| 1080 | 10 | 2.0 | 6.2 | 6.2 | 5.8 | **10.5** | **2.7** |

## CONCLUSION

The relation between pollution load in olf and the perceived air quality should be approximated by a root relation. If the measurement results are already evaluated in this way one can simply add and substract pollution loads by using root mean square rules and the results show better agreement with the experience.

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