An interaction model for odour intensity

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ABSTRACT
A laboratory study has been carried out to investigate the exposure response relationships between perceived air quality (PAQ) and concentration of pollutants. The objective was to develop an interaction model for odour intensity, which allows predicting the perception of a combination of odours on base of the data for the single pollution sources. In the experiments 10-12 persons assessed the PAQ in $decipol_B$ directly. Three different materials served as pollution sources. The exposure response relationship of the single pollution sources and the combinations of at maximum two sources were investigated. Afterwards it was calculated the exposure response relationship of the combination using different mathematic models. The comparison between experimental and calculated data has shown that the perceived air quality of a combination of two different pollution sources can be added or subtracted quite similar to different sound levels. A simplification in the equation of the exposure response relationships allows a easy and fast calculation of the PAQ.

INDEX TERMS
Perceived air quality, Calculation, Human response, Material emission, Ventilation rate

INTRODUCTION
Among the removal of thermal loads the removal of emissions from pollution sources is a main task of a HVAC system. For that, a certain airflow rate is needed. An incorrect calculation of the airflow rate leads either to a dissatisfying performance of the system or to higher operating costs because of a higher energy consumption. For thermal loads the airflow rate can be calculated easily for given parameters of supply air. To calculate an airflow rate regarding to the specific pollution load in a room a simple mathematical model does not exist. Until now the best results one can get by using a graphical model (Knudsen, Valbjorn, Gunnarsen et al., 1999). This model serves to predict the perceived air quality (acceptance) in the room for a certain concentration of different pollutions by graphical combination of the exposure response relationships for the single pollution sources. The specific exposure response relationships are ascertained for constant source strength. For practical use this model is not really suitable, because the knowledge of exposure response relationships of each pollution source in the room is required. Furthermore the study has been carried out with untrained people. Their votes are influenced by the thermal parameters of the assessed air (Fang, 1997). Therefore the exposure response relationships of the single pollution sources are only applicable in praxis for equal specific enthalpy.

A study has been carried out with the objective to develop an interaction model for odour intensity, which allows predicting the perception of a combination of odours on base of the data for the single pollution sources. A benefit of using the odour intensity as measure for

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PAQ is their independence of the specific enthalpy. That was found in a study, in which trained people were assessing the odour intensity at different thermal parameters (Böttcher, 2003). There was no dependence of the intensity votes on the specific enthalpy. Independent from the specific enthalpy it was observed, that the perceived air quality did not change with the relative humidity of the assessed air. Therefore, to use the exposure response relationships for intensity from laboratory in praxis the same specific enthalpy is not needed but the same relative humidity in laboratory and field. In mechanical ventilated buildings these requirement can be assumed as fulfilled.

To develop mathematical model one needs information about the single pollution sources like building materials, persons, furniture, and polluting potential of the supply air and the perception of the combination of these sources too. The model for the calculation of the perceived air quality should be as easy as possible to use. Therefore the mathematical description of the exposure response relationship between odour concentration and perception (with PAQ as measure) should be very simple.

METHOD

The study was carried out in the laboratory. In the experiments 10-12 persons assessed the PAQ. The persons are trained to assess the PAQ directly in decipol$_B$ by comparing the intensity of air polluted by an unknown odour with the intensity of different 2-propanone concentrations. The index "B" is used following a suggestion to differentiate the methods to assess the perceived air quality in decipol (Fitzner, 2000).

The following three different materials served as pollution sources:

- 2-Propanone (A=0,002 m²),
- carpet (A=0,08 m² to 0,16 m²),
- floor covering (A=0,48 m² to 0,64 m²)

2-Propanone was filled in a bottle with a diameter of 0.05 m². The material surface of carpet and floor covering depends on the desired level of PAQ in the experiments. It was tried to carry out the experiments between a PAQ of 5 decipol$_B$ for the lowest and 20 decipol$_B$ for the highest concentration of emissions in the assessed air. The limitation of 5 decipol$_B$ was chosen to eliminate an influence of the odour threshold and the other limitation was chosen, because of using 17 decipol$_B$ as strongest milestone.

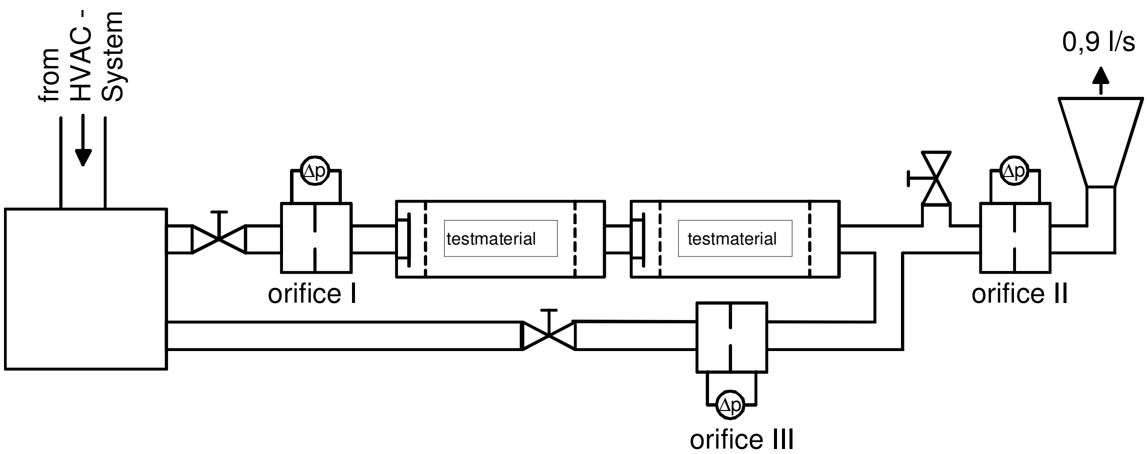

Figure 1 Experimental setup in the experiments to the addition of odours

The experimental setup in the experiments to the addition of odours is shown in Figure 1. The materials were placed in special test chambers made of glass separately. In the experiments of combinations of materials two test chambers were build in line. The first test chamber was supplied with unpolluted air from the HVAC-system only. The second chamber was getting polluted air. In the experiments with the single materials one chamber was used only. The concentration of pollutants in the air was affected by diluting with unpolluted air. Four different concentrations of pollutants in the assessed air were investigated (35 %, 50 %, 75 %, and 100 %). The different air flow rates were controlled with measurements of the pressure differences at orifices, which were calibrated before starting the test series.

The exposure response relationship of the single pollution sources and combinations of at maximum two sources were investigated. The experiments were carried out several times and in reverse order of the test chambers too.

In a second step it was calculated the exposure response relationship of the combination on base of the data of the single materials. Therefore four different mathematical models were used. Afterwards the calculated and the assessed perceived air quality were compared for each model. A linear regression was carried out for the calculated PAQ and the gradient of the function served as measure for the quality of the used model. In case the gradient is 1 an ideal correlation between calculated and assessed perceived air quality is gained.

RESULTS

Among olfactory investigations analytical measurements of the concentration in the assessed air have been carried out to control constant emission conditions. In the measurements a gas monitor (Brüel&Kjaer, Type 1302) for 2-propanone and a GC/MS for the emissions from the other investigated materials were used. It was found, that the source strengths of the materials were constant for the duration of an experiment.

In Figure 2 the results of the olfactory assessments are shown. The median of the single votes of the persons has been used as mean value for the perceived air quality at a specific concentration. This results from the analysis of the frequency distribution. In the figure the result of a single experiment is plotted. This result represents the typical relation between concentration and PAQ for each material which was found several times.

In Figure 2 is shown the perceived air quality in decipol$_B$ (y-axis) at the investigated concentrations (x-axis). The result of the experiment without any pollution sources demonstrates that the setup itself was not polluting the air. For each material the exposure response relationship can be described with a logarithmic function. The function (1) is defined by two parameters ("a" and "b"). The indices are marking the investigated material.

$$PAQ = a_i \cdot \log_{10}(b_i \cdot C) \qquad (1)$$

By knowing the exposure response relationship of a material one can calculate the air flow rate of unpolluted air to get a certain perceived air quality for the case, that the material is the only pollution source in the room. For that purpose one has to find out the ratio between material surface and air flow rate at a certain PAQ. Next, the reciprocal of this ratio has to be multiplied with the amount of the used material surface in the room. The result is the air flow rate in l/s which is necessary to dilute the existing pollutions to get the desired PAQ.

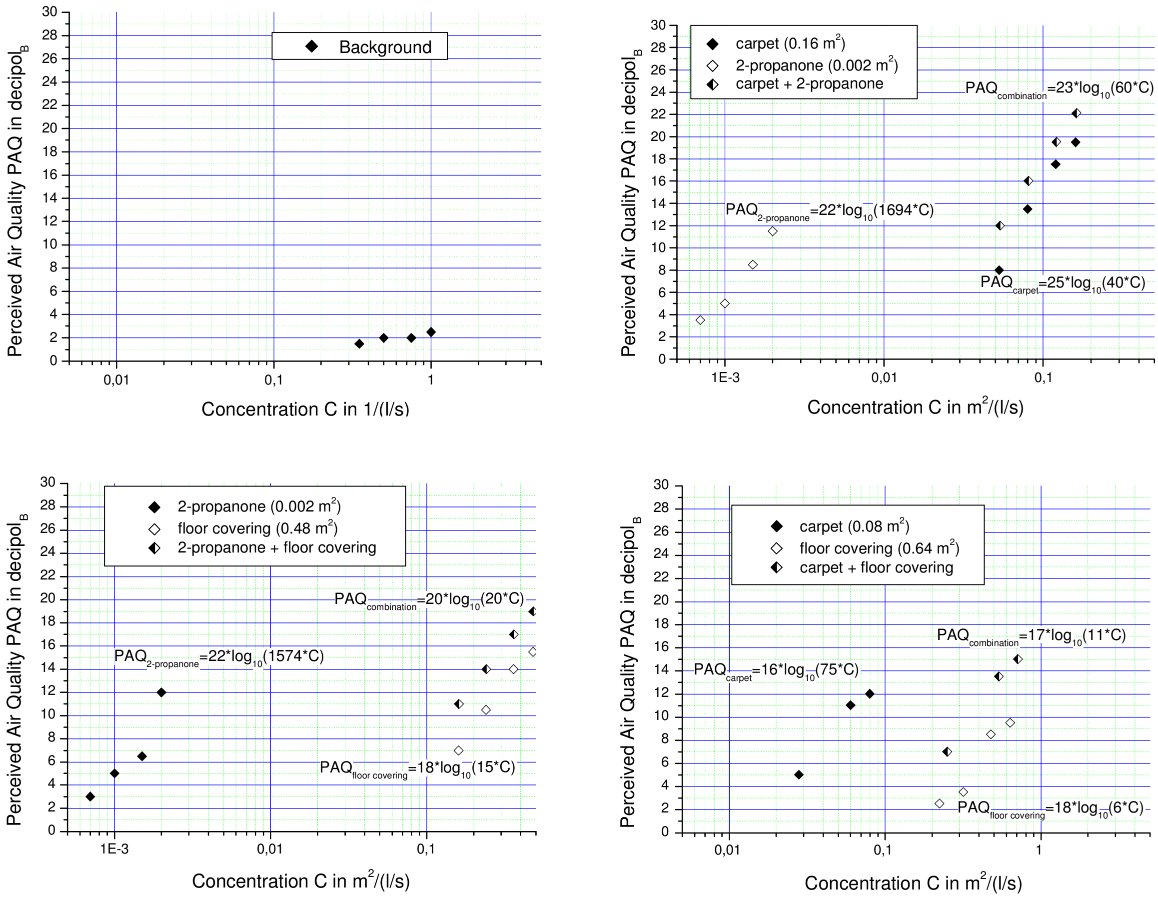

Figure 2 Results of the olfactory assessments (Böttcher, 2003)

In Figure 3 is demonstrated a comparison between calculated PAQ and assessed PAQ for the model which is called “Level addition”. The name of this model has been chosen because it is very similar to the addition of sound levels. With the “Level addition” the best results for predicting a perceived air quality have been gained. The gradient of the linear regression is 1.05 (R^2=0.99). That means that the calculated perceived air quality is in average 5 percent higher than the assessed perceived air quality. The gradients of the linear regression for the other models are significant higher. They are shown in Table 1.

Table 1 Results of the linear regression for the used models (Böttcher, 2003)

Name of model	Equation	Gradient of the linear regression	Difference from ideal case in %
linear Addition	$PAQ_{1+2} = \sum_{i=1}^{2} PAQ_i$	1,28	28
logarithmic Addition	$PAQ_{1+2} = \sum_{i=1}^{2} 10^{PAQ_i}$	0,82	18
Level addition	$PAQ_{1+2} = \frac{\sum_{i=1}^{2} a_i}{2} \cdot \log_{10} \sum_{i=1}^{2} 10^{PAQ_i / a_i}$	1,05	5
Vector addition	$PAQ_{1+2} = \left\lvert \vec{\Psi}_{1+2} \right\rvert = \left\lvert \sum_{i=1}^{2} \vec{\Psi}_i \right\rvert$	0,63	37

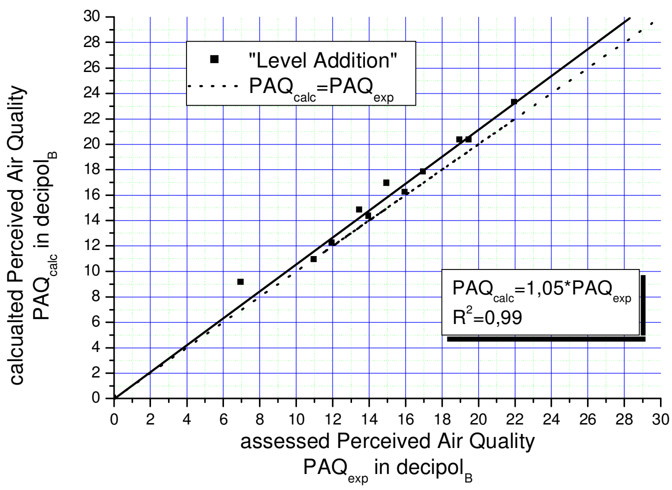

Figure 3 Comparison between calculated and assessed perceived air quality for the model "Level addition" (Böttcher, 2003)

With the "Level addition" one is able to calculate the expected PAQ of a combination of two odours on base of the data of the single pollution sources. With the exposure response relationship of the combination the air flow rate to dilute the emission from both pollution sources can be calculated. The way of calculation of the air flow rate is the same as for single pollution sources. The material surface of the combination is the sum of the single surfaces of the materials.

In the next step it was tried to simplify the model of "Level addition", because in the existing form it is even too complicated for practical use. On the one hand the exposure response relationships for the materials are needed, which have to be specified in laboratory. On the other hand one can not calculate the perceived air quality if you have single $decipol_B$ values only. But this is often needed, for instance in case to find out the pollution load of a component of a HVAC-System. Here, the PAQ has to be assessed before and after the component and afterwards the pollution load of the investigated component can be calculated by subtracting the $decipol_B$ values.

To answer the question how to simplify the model, it is suggested to set the parameter "a" as constant, comparable to the acoustics where the logarithmic functions for the relationship between sound level and sound intensity have a constant factor of 10. An analysis of the parameter "a" in the single functions of the investigated materials for the exposure response relationship was done. It was found, that these parameters are in a range between 16 and 25. Therefore it is suggested to set $a = 20$. The simplified function for the exposure response relationship is shown in equation 2:

$$PAQ = 20 \cdot \log_{10}(b_i \cdot C) \tag{2}$$

With equation 2 a good correlation between concentration and assessed PAQ is gained too. There are no significant changes of R^2 in the single correlation functions in comparison to the functions with two parameters (equation 1). Also the calculations carried out with the simplified exposure response relationships are leading to a good correlation between calculated and assessed PAQ. The gradient of the linear regression is 1.05 (R^2=0.98).

The benefit of simplifying the model is that now figures can be created which are transferring the logarithmic calculations in linear relations. Thereby the calculation of a perceived air quality is very easy and fast to do. The following Figure 4 is showing the addition and subtraction of single decipol$_B$-values of pollution sources with different intensity.

Addition: Subtraction:

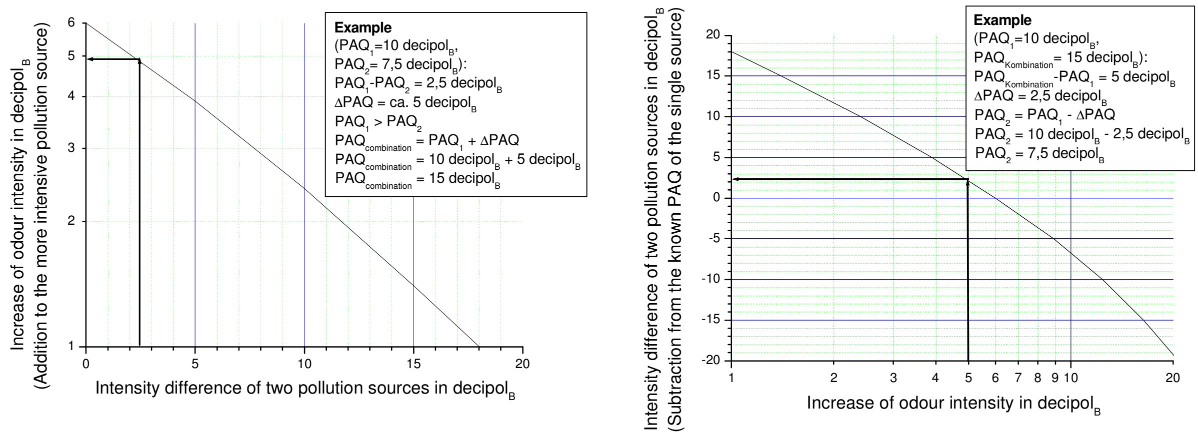

Figure 4 Addition or Subtraction of different perceived air qualities (Böttcher, 2003)

DISCUSSION

The suggested simplification of the model with a constant parameter “a” has to be checked in further investigations if a value of 20 leads to good correlations for other materials too. Furthermore the influence of sorption has to be more investigated. Due to the small surfaces of materials and the very compact experimental set-up a significant influence of adsorption on the results of the assessments has not been found in this study. This results from measurements of the concentrations of emissions in the assessed air.

CONCLUSION

It was found an interaction model for odour intensity to calculate the exposure response relationship of a combination of two different pollution sources on base of the data for the single pollution sources. The study has shown that different pollution sources can be added or subtracted quite similar to different noise levels. With the model an airflow rate can be calculated regarding to the existing pollutions in a room.

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REFERENCES

Böttcher O. 2003. “Experimentelle Untersuchungen zur Berechnung der Empfundenen Luftqualität”. Ph.D. Thesis. Technical University Berlin

Fang L. 1997. “Impact of Temperature and Humidity on Perceived Indoor Air Quality”. Ph. D. Thesis. Technical University of Denmark

Fitzner K. 2000. „Stand der Entwicklung bei der olfaktorischen Bestimmung der Luftqualität in Innenräumen“. Proceedings of DKV-Conference. Vol. IV. pp 37-46

Knudsen H, Valbjorn O, Gunnarsen L, Nielsen PA. 1999. „Acceptability of Air with Mixtures of Emissions from Building Materials“. Proceedings of the 8th International Conference on Indoor Air Quality and Climate-Indoor Air’99. Vol. 2. pp 576-581. Edinburgh: Indoor Air’99