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The Decipol Method

At the 4th International Conference on Indoor Air Quality and Climate, held in Berlin In August of 1987, Professor Ole Fanger of Denmark presented a Plenary Lecture titled "The Solution to the Sick Building Mystery." The solution he presented was a method for subjectively evaluating IAQ based on sensory perception — odor and irritation in particular. He introduced a new unit, the decipol, which he compared to the decibel for weighted sound pressure level and the lumen or lux for illumination intensity. His presentation was amusing and engaging: so much so that many in the audience took it as entertainment rather than as a serious proposal.

In fact, it was serious, and the decipol has gained great prominence in the indoor air field, especially in Europe where Fanger is a very influential participant in standard setting among other things. It is so prominent that in the recently completed European Audit project, it was used to assess each of the buildings — the final report of the project compares the values obtained by the trained panels assessing perceived air quality (PAQ). The results were disappointing to many because there was little to no correlation with most other measurements nor to occupants' symptoms reported on questionnaires.

Arguments have ensued about the utility of the decipol method, and the focus of this ***BULLETIN*** is on that discussion. In this issue, we take the unprecedented step of publishing a feature article prepared by an author other than the editor; we're pleased to present a paper submitted by Philomena Bluyssen. Previously we have often published letters to the editor, but not feature articles. We have taken this unusual step because the decipol is both important and controversial. As usual, we hope to inform our readers through an intelligent discussion including various perspectives on a controversial and important topic — in this case, the methodology known as the decipol method.

While Fanger is widely identified with the decipol, much of the development and application work to date has involved others either now or formerly working at his laboratory at the Danish Technical University. One of these is Philomena Bluyssen, now of TNO in the Netherlands, who wrote her doctoral thesis on the decipol method. I first met Philo at the "olf bar" at Healthy Buildings '88. I found myself inept at identifying the olf levels of the 2-propanone (acetone) concentrations coming from the several jars on the bar — but it was fun trying. Since then, Bluyssen has been involved in many projects using the decipol, but none as large or important as the European Audit Project, a study of 56 buildings in 9 European countries using standardized methods.

The decipol measurements were conducted by trained panels, and much of the paper focuses on the results of that study. There were not strong correlations between the decipol ratings of the panels and the measurements by questionnaire or chemical instruments. While the final report of the audit project states that such correlations were not expected, this assertion is in direct contradiction to the presumed purpose of the decipol method and of many people's expectations if not understandings of the European Audit Project. Many ask why so much money was spent on the measurements if they are not useful predictors of something of interest.

Readers not familiar with the Audit Project will probably find the Addition (page 6) and Discussion (page 7) sections of the paper most interesting. We follow with comments from researchers at the Building Research Establishment in the UK and from Professor Fanger and his colleagues at the Danish Technical University. There are some important issues there that go beyond the decipol method and are relevant to subjective evaluation of IAQ, sick building syndrome, and other relevant topics.

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The Decipol Method: A Review

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Introduction

Chemical and physical measurements have frequently been unable to identify reasons for complaints about bad indoor air quality. In many cases, the human senses are superior to chemical analysis for assessing how air is perceived. The striking factor of the human nose, as compared to physical/chemical instruments, is its extreme sensitivity to low concentrations of many chemical substances and its ability to discriminate among them. Furthermore, psychological effects cannot be mimicked by detectors. Therefore, a sensory evaluation of indoor air pollution is often necessary.

Fanger introduced a measuring unit to quantify sources of perceived air pollution (1). Any source that emits molecules which can be perceived by the human nose is considered; this includes odorants and irritants. This unit, the olf, is related to the human nose and to human bioeffluents. One olf is defined as the emission rate of air pollutants (bioeffluents) from a standard person. Any other pollution source may be quantified by the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source. A standard person is the average sedentary occupant in thermal comfort. The definition is based on studies on bioeffluents from more than one thousand subjects at the Technical University of Denmark. 168 subjects evaluated the air polluted by bioeffluents (2,3).

A second unit, the decipol, was introduced to quantify perceived air quality by humans. One decipol is the perceived air pollution caused by one standard person (one olf) ventilated by 10 L/s of unpolluted air. The relationship betwcen the decipol and the percentage of dissatisfied judges is shown in Figure 1.

The two units, olf and decipol, make it possible to determine a comfort equation for air quality in a space, which is defined as follows (4):

$$Q = 10 \bullet G/(C_i - C_o) \bullet 1/\varepsilon_v \qquad [1]$$

with:
Q = ventilation rate required [L/s]
G = total pollution load [olf]
C_i = perceived indoor air quality, desired [decipol]
C_o = perceived outdoor air quality [decipol]
ε_v = ventilation effectiveness

The required ventilation is proportional to the pollution load. Based on these two units, the so-called decipol method was developed. The decipol method comprises either a panel of circa 10 persons who are trained to evaluate the perceived air quality in decipol or an untrained panel (5). A method to train a panel to evaluate perceived air quality in decipol has been developed (6,7).

In a recently finished European project, "European Audit project to optimize indoor air quality and energy consumption" (IAQ-Audit project) (8), trained sensory panels were used to investigate 56 office buildings all over Europe. Current methods were also used.

This publication describes the decipol method and its current level of development. A critical review of this method is given as well as necessary developments for the future.

The Decipol Method

Different panel procedures may be used to measure perceived air quality:

- A representative untrained panel voting either on a binary (yes - no) acceptability scale (9) or on the continuous acceptability scale. In the latter, mean votes may be transformed to a percentage of dissatisfied and from there further to decipol levels (5).
- Careful selection of a panel followed by training to make direct measurements in decipol possible (7).

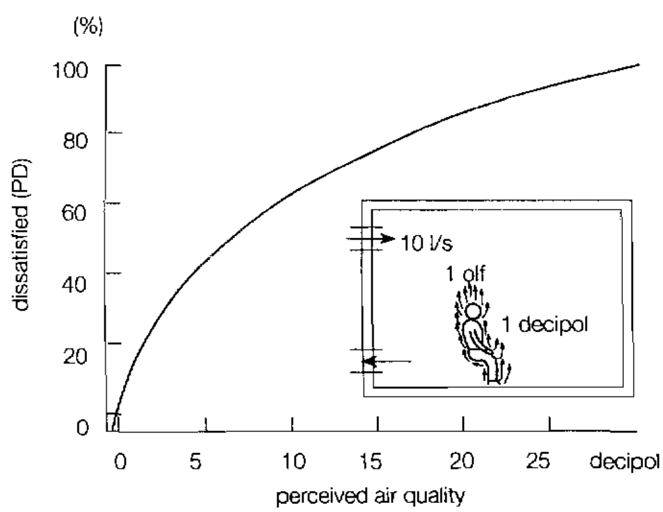

Figure 1 - The curve defines the relationship between the percentage of dissatisfied judges and the perceived air quality in decipol (1).

Untrained Panels

The size of an untrained panel depends on the required precision of the mean votes. Votes may be given a value assuming clearly acceptable is 1 and clearly not acceptable is -1, with 0 being the midpoint. Mean acceptability votes are calculated using simple arithmetic means. By the previously established relationships (10), the acceptability votes can be transformed to a percentage of dissatisfied and perceived air quality (PAQ) in decipol for further calculations and comparisons.

The uncertainty of assessments of an untrained panel can be described by the $(1 - \alpha)$ confidence interval for the mean acceptability vote (μ). The (1 - a) confidence interval is a stochastic interval that in (1 - a) • 100 percent of the cases includes the true value: in this case, the mean acceptability vote. If random samples of size n are taken from a normally distributed population, than the statistics has a Students distribution with n - 1 degrees of freedom. For $n \geq 30$, the sampling distribution is nearly normal. The 95% confidence limit for estimation of the population mean μ is given by:

$$\text{for } n \geq 30 : x \pm 1.96\sigma/\sqrt{n} \quad [2a]$$
$$\text{for } n < 30 : x \pm t_{.975}s/\sqrt{n} \quad [2b]$$

with:
x = estimated mean
σ = standard deviation
n = size of sample
s = estimated standard deviation
$t_{.975}$ = t-distribution of 95% confidence interval

Standard deviations of votes by an untrained panel are shown in Figure 2. The standard deviation is defined as the square root of the variance. The variance is the sum of the quadratic differences between the mean and each single evaluation. From Figure 2, it follows that the mean standard deviation in the area -0.3 to 0.3 of the acceptability scale is approximately 0.5. For a standard deviation of 0.5, a relationship between the 95% confidence limit width and the size of n (number of untrained panel members) is presented in Figure 3. For example, the numbers of untrained panel members required for a 95% width of 0.1 and 0.25 are approximately 380 and 70, respectively.

Trained Panels

A reference is required when a panel has to be trained to evaluate perceived air quality directly in decipol. The units for PAQ (decipol) and pollution source strength (olf) introduced by Fanger (1) are based on the reference of human bioeffluents. Human bioeffluents comprise a large number of chemical compounds and vary considerably from person to person. A reference that is easy to measure and to produce was therefore selected: 2-propanone (6). The production of this reference source is based on passive evaporation and is introduced to the human nose by a constant airflow coming out of the so-called decipolmeter (Figure 4). The relationship between the PAQ in decipol and the 2-propanone concentration in air was determined by 265 persons (6) (Figure 5). This relationship is used to train people in evaluating air quality directly in decipol.

Four different 2-propanone concentrations (2, 5, 10, and 20 decipol) generated by four decipolmeters, called the "milestones," serve as the reference for the panel members. During the training, several unknown decipol levels (2-propanone concentrations) are evaluated several times using the four milestones as a reference. After each evaluation the correct answer is given. During the training, the panel members are also exposed to other pollution sources than 2-propanone. These other sources comprise several common materials from buildings.

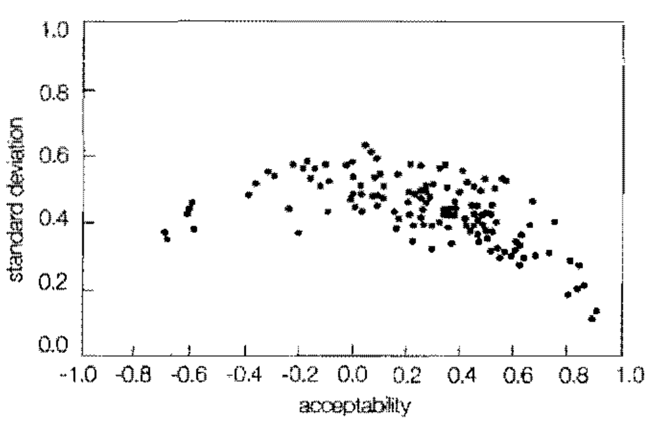

Figure 2 - Standard deviation on acceptability votes with an untrained panel (10).

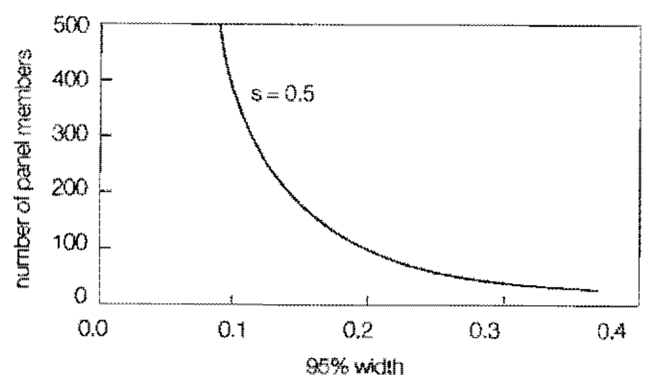

Figure 3 - 95% width related to number of untrained panels for an estimated standard deviation of 0.5.

The equipment required to train a panel comprises circa 12 decipolmeters, equipment for production of 2-propanone, and a "Zero-decipol room" (11, 12, 13).

Performance of Trained Panels

In the current procedure to train panel members to evaluate PAQ in decipol, the training level of a panel or panel member is tested with unknown 2-propanone concentrations in air and several other unknown air pollution sources, which each panel member has to compare with four known 2-propanone concentrations in air. The training level can be determined by comparing the given votes to the correct values for the 2-propanone levels and by using the repeated votes and/or the standard deviation on the panel vote for the unknown sources. In the European IAQ-Audit project, exams were used to select a panel member and a whole panel (11). The allowed error limits originally set for these exams depended on the PAQ level of the samples.

Some methods are available to calculate an index that represents the panel performance (6). The disadvantage of all these calculation methods is the dependency on the chosen PAQ level and the number of unknown (2-propanone) sources. A comparison of different calibration tests and panels could only be made if the chosen PAQ levels were identical.

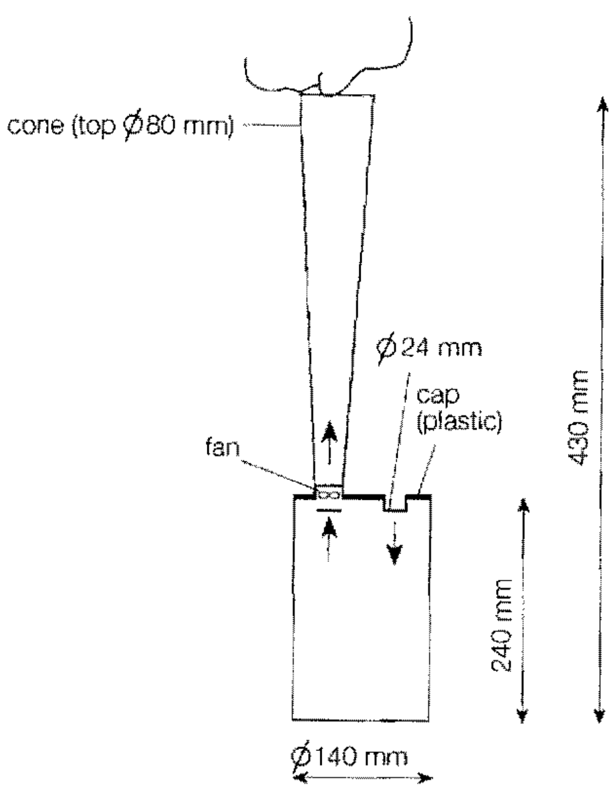

Figure 4 - The decipolmeter.

Therefore, three new performance factors were defined (14, 15). The Individual Performance Factor (IPF) describes the performance of a panel member with 2-propanone, the Panel Performance Factor (PPF) describes the performance on the whole panel with 2-propanone, and the Deviation Performance Factor (DPF) describes the panel performance on pollution sources other than 2-propanone. The three performance factors were used to calculate the performance of eight panels in the IAQ-Audit project.

The Individual Performance Factor is defined as (with the ideal vote (voted = correct) taken as IPF = 0):

$$IPF = (voted - correct) / (A * correct + B) \quad [3]$$

with:
IPF = individual performance factor
voted = voted PAQ level [decipol]
correct = correct PAQ level [decipol]
A = tangent of angle difference between lines
B = intersection with Y-axis

The values for A and B are:
PAQ < 5 decipol: A =- 3/28 and B =+ 59/28
PAQ >= 5 decipol: A =+ 4/28 and B =+ 24/28

If the allowed errors change, the coefficients in the formula change as well. The mean value of the IPF and the standard deviation of the IPF give an indication of the quality of the panel member related to 2-propanone concentrations. Note that the IPF is not the absolute error. This means that too high a vote and too low a vote may result in a mean IPF of zero. Therefore, the deviation on the IPF must be considered too and should be as small as possible. The same approach is possible for the whole panel. The mean IPF value of the performance for the whole panel is called the Panel Perfor-

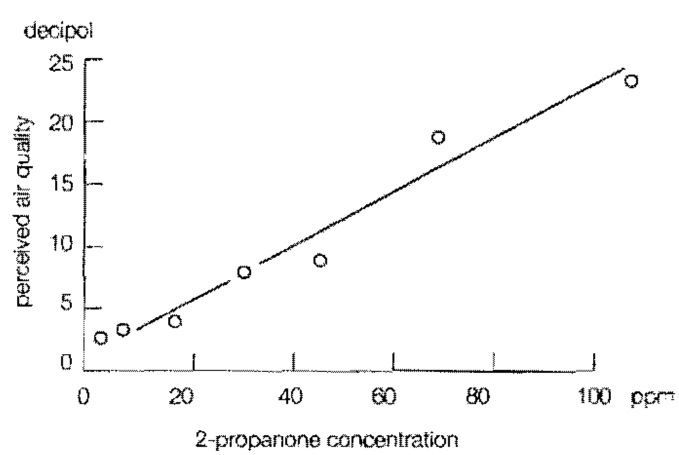

Figure 5 - Relation between perceived air quality and 2-propanone concentration in air, determined by 265 persons (7).

mance Factor (PPF). The PPF and the standard deviation on the PPF give an indication of the quality of the whole panel related to 2-propanone concentrations.

Taking the error limits into consideration, the IPF and PPF values of the eight panels were calculated. The mean IPF value for each PAQ level ranged between +0.5 and -0.5, and the PPF value between 0 and 20 decipol was independent of the PAQ level. The PPF ranged from -0.05 to +0.50. The standard deviation on the PPF, which presents the spread of IPF values of the panel members, was between 0.3 and 0.45 for the majority of the panels.

The panel performance on pollution sources other than 2-propanone can be described by the Deviation Performance Factor (DPF). For sources other than 2-propanone, the correct answer is not defined and therefore an evaluation of the vote is not yet possible as such. Therefore, with the DPF, the allowable standard error was not considered, but rather the mean standard error on votes of pollution sources other then 2-propanone (standard error is defined as the standard deviation divided by the square root of the number of panel members in one panel). For the DPF, the mean standard error of all panels is defined as index = 1. The mean behavior of a sensory panel was determined by taking all the field data from the eight panels in the IAQ-Audit project. The DPF is defined as:

$$DPF = \sigma_x / (a \cdot PAQ^2 + b \cdot PAQ + c) \qquad [4]$$

with:
$a = -0.0026$
$b = +0.09924$
$c = +0.1262$
σ_x = standard error

Because most of the IAQ-Audit data ranged from 0 to 10 decipol, the equation is only valid in this interval. Future projects can expand this interval and may possibly change the coefficients a, b, and c in the equation.

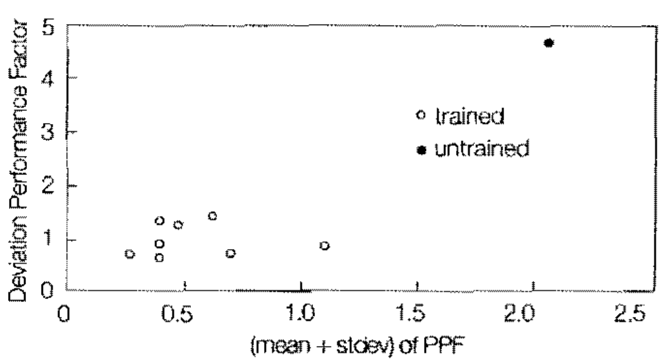

Figure 6 - Comparison between PPF and DPF plus standard deviation for each of the eight panels in the IAQ-Audit project.

The DPF ranged from 0.7 to 1.5. The standard deviation on the DPF was between 0.2 and 0.4. The DPF value between 0 and 10 decipol was independent of the PAQ level.

An important question to ask now is: Does the performance of a trained panel with respect to 2-propanone (PPF) relate to the performance of a trained panel with respect to field evaluations (DPF)? For the PPF, it was stated that not only the mean is important to consider but also the standard deviation of the PPF. Figure 6 shows a comparison between the PPF (plus the standard deviation on the PPF) and the DPF for each of the eight IAQ-Audit panels. As can be seen, no relationship is present. However, it must be noted that this comparison comprised only 8 points and it concerned panels which were all trained and had passed exams 1 and 2 as defined in the IAQ-Audit project (11), so small differences can be expected.

To give an idea on how an untrained panel performs expressed in PPF and DPF, a similar calculation was made for an untrained panel. For the calculation of the PPF, the 8 2-propanone evaluations of the 54 persons that participated in the selection test for the IAQ-Audit project in the Netherlands were used (16). The mean PPF was 0.98 and the standard deviation on that PPF was 1.07. The DPF was calculated using the assumption that the standard deviation of an untrained panel is 0.5 on the acceptability scale. For the levels 2, 5 and 10 decipol, the DPF was then calculated using an untrained panel of 11.4 persons (average panel size IAQ-Audit project) and using the previously established relationships between acceptability vote and decipol level (10). The DPF was 4.6. As can be seen in Figure 6, the PPF and DPF of an untrained panel are indeed much larger than for trained panels. However, the DPF is now based on acceptability votes of an untrained panel and the PPF on evaluations in decipol by another untrained panel.

More panel data are required to be able to make a definite conclusion.

Comparing Trained and Untrained Panels

Comparing the performance of trained and untrained panels is not simple since the primary voting scales are different. Table 1 presents the number of untrained panel members required to match with the average IAQ-Audit panel. These data are based on the presented deviations on the votes of a representative untrained panel, the average performance of a trained panel according to the European IAQ-Audit project, and the assumption of normal distribution. The calculation procedure was as follows. The standard error from the average IAQ-Audit panel was calculated for the decipol levels 2, 5, and 10, using the following formula:

$$\sigma_x = (-0.0026 \cdot PAQ^2) + (0.09924 \cdot PAQ) + 0.1262 \quad [5]$$

For each decipol level, the acceptability vote was estimated using the previously established relationship between acceptability vote and decipol level (10). The required standard error on these acceptability votes was determined. The required number of untrained panel members is than calculated from the following equation:

$$\text{required no. of untrained} = (\text{expected } \sigma / \text{required } \sigma_x)^2 \quad [6]$$

The expected standard deviation from an untrained panel is determined from Figure 2 using the average standard deviations for an acceptability level between -0.3 and 0.3 (the area in which most PAQ levels occur in the indoor environment): a standard deviation of 0.5. From Table 1, it follows that if the air quality in the buildings to be considered is equally distributed from 2 to 10 decipol, an average of approximately 280 untrained panel members is required to match the average panel in the IAQ-Audit project.

Addition

For the olf/decipol method, the question has been investigated whether a simple addition of pollution loads (in olf) may be used for estimating the combined sensory effect of different sources. A trained panel was used to investigate this simple addition method for several pollution sources (17). Addition of olfs from different pollution sources occurring in a space seemed, as a first approximation, a good prediction of the total olf-load of that space.

A study performed by Cornelissen *et al.* (18) did not result in the same conclusion. They studied the addition of source strengths from 11 materials. A trained panel evaluated single materials and combinations of these materials. In Figure 7 the evaluated source strengths of the combinations are given as functions of the addition of the separate source strengths for each of the 11 combinations evaluated. From Figure 7 it appears that the panel evaluated a combination lower than the addition of the separate source strengths would predict. Considering the results in more detail, it seems that for most of the combinations the evaluations lie around the highest of the two separate evaluations. Figure 8 shows that the total source strength in olf lies between 25% above or below the highest of the two single source strengths.

In the study of Bluyssen (17), the total olf-value ranged from 0.2 to 1 olf, while in the study from Cornelissen (18), the total olf-value was in general above 1 olf. Therefore, for low olf-values (<1 olf), the simple addition method might be valid; while for higher olf-values (>1 olf), the evaluation of a combination might be less than the sum of the separate values.

However, it has recently been shown that individual materials can be characterised by their exposure-response relationships between the concentration of air pollutants and perceived air quality (19). The exposure-response relationships differed between the materials and also from the corresponding relationship for human bioeffluents (Figure 1). Consequently, the sensory emission rate for a material expressed in olf/m^2, may, rather than being constant, change with the pollution concentration in the air. It can be discussed whether this is a problem of exposure-response with concentration or whether it is perhaps an additivity problem. Furthermore, studies on combinations of materials and exposure-response relations still need to be done.

Cornelissen (18) also studied the evaluation of one material in different quantities. Two materials were evaluated in three quantities two times. With the first evaluation, the trained panel was not allowed to compare the PAQ of the three different quantities. With the second evaluation, the panel was asked to compare the

Perceived air quality [decipol]	Average std. error for IAQ-Audit panel [decipol]	Acceptability [acc. scale]	Estimated required std. error [acc. scale]	Estimated required no. of untrained persons
2	0.31	0.30	0.045	125
5	0.56	0.06	0.030	280
10	0.86	- 0.14	0.030	280

Standard error [decipol] = $-0.0026 \cdot PAQ^2 + 0.09924 \cdot PAQ + 0.1262$
PAQ = perceived air quality level [decipol]

Table 1 - Corresponding votes of perceived air quality (decipol) and acceptability together with required standard errors on votes and calculated required number of untrained panel members, assuming an expected standard deviation of 0.5 on the acceptability scale.

PAQ of three quantities of each material. Table 2 shows the results of this study. From this table it appears that the results differ considerably when asking the panel to compare or not. Besides the annoyance or type of sensory stimulus, the intensity seems to be an important factor. When different amounts of materials are offered without having the opportunity to compare, the panel seems to give similar decipol levels to the different quantities of the same material. Furthermore, the results give the impression that without a comparison opportunity, it is only the type of sensory stimulus that is evaluated and not the intensity. However, this study only comprised two materials. More research is required to confirm these findings. If these findings are indeed true, one should take care when performing comparison studies.

Discussion

Olf and Decipol

Figure 1 shows the basic relationship on which the whole olf/decipol theory is based. The error margins of this curve are, however, not presented and several investigators (Oseland (20), among others) have questioned this. It was suggested that the basic olf/decipol experiment be repeated by assessing the air in a test chamber with a number of sitting persons at various recorded ventilation rates. In other words, the large auditorium study (3) would be repeated in a controlled environment. According to Oseland, such an experiment would allow the PD scores for a single olf at a specific ventilation rate to be obtained.

Other investigators have repeated the bioeffluent studies with subjects of other nationalities. In a Japanese study (21), 107 subjects served on panels to judge the acceptability of bioeffluents from 54 other subjects who served as occupants in a climate chamber. This resulted in a ventilation rate of 7.1 L/s per person corresponding to 20% dissatisfied visitors (1.4 decipol). The percentage of dissatisfied as a function of perceived air quality in decipol agreed well with the results of Fanger (1). In Yugoslavia, two auditoria were occupied by more than 700 persons (in groups of 37 to 191) during 40 experiments where 44 judges evaluated the acceptability of the air (22). 20% dissatisfied corresponded to a ventilation rate of 3.4 L/s per person (2.1 decipol). These results did not agree with the results of Fanger (1).

The Comfort Equation

The comfort equation is used to calculate required ventilation rates when source strengths of different sources can be added and steady state conditions can be assumed (4). However, the assumption that source strengths of different sources can be added needs to be re-evaluated. The results from studies performed by Cornelissen (18) and Knudsen (19) indicate that the simple addition theory may be too simple.

Furthermore, sorption effects are not taken into account. During transient conditions in real spaces, sorption processes on surface materials may affect the concentration of pollutants in the air. By adsorption, some material surfaces may work as air cleaners whereas during other conditions, the surfaces may release pollution by desorption and thereby increase the pollution level in the air — for example, cigarette smoke (23). Information on sorption processes is still at a rather rudimentary level. Research is required to model the impact of sorption processes on the perceived air quality in spaces during the transient operation of ven-tilation systems. This information is needed

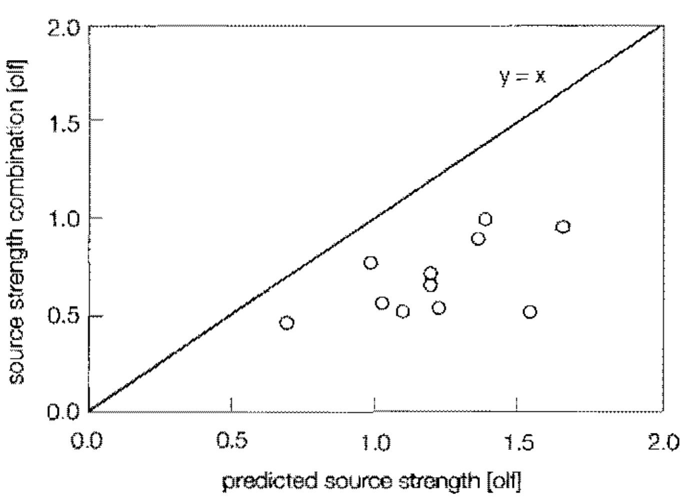

Figure 7 - The evaluated source strengths of the combinations as a function of the predicted by addition of the two single source strengths.

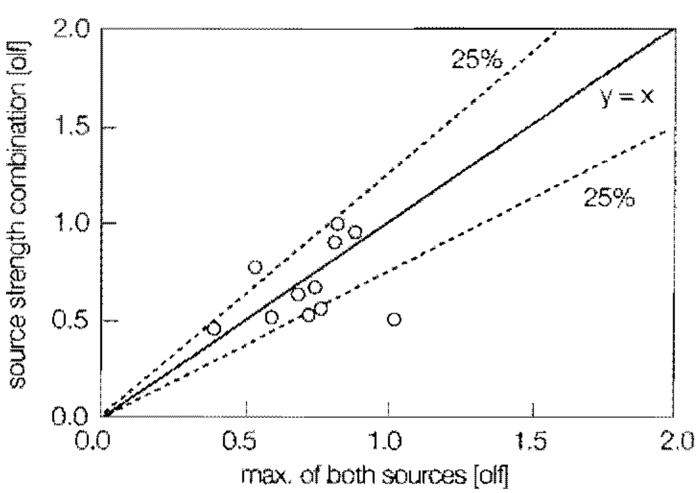

Figure 8 - The evaluated source strengths of the combinations as a function of the highest of the two single source strengths.

to predict required ventilation rates, optimal ventilation strategies, and to select the right materials to assure good indoor air quality.

A certain composition of air contaminated by emissions from materials may be perceived differently at different temperatures and humidities. Knowing the effects of temperature and humidity on perception is therefore important when modelling air quality in real spaces. These effects should be included in the comfort equation.

The comfort equation is also used to calculate the pollution source strengths of a ventilation system and its components. The ventilation rate is, in this case, equal to the airflow going through the system and the perceived air quality before and after a component or the whole system are taken as the outdoor and indoor levels in equation [1]. Several studies have indicated that air filters can be one of the main polluters in ventilation systems. Two studies showed that when the airflow is increased, the source strength of the polluting filter increased proportionally (24,25). It is remarkable, however, that in both studies the perceived air quality levels before and after the filters did not change significantly with the airflow. It should therefore be investigated whether the comfort equation is suitable to calculate source strengths of a ventilation system and its components.

Ventilation Rates and Levels of Perceived Air Quality

A draft European pre-standard was issued by CEN TC 156 (26). In this document, for the first time, pollution sources other than occupants are taken into account and any source that emits molecules which can be perceived by the human nose is considered. The draft European pre-standard prENV1752 (26) proposes figures for different levels of ventilation rates in office buildings (Table 3). These figures are recommended only for low-polluting building materials and furnishings and for a ventilation effectiveness of 1. They are based on air quality as perceived by persons entering a room coming from fresh, clean air. Category A corresponds to 15% dissatisfied (1 decipol) only, while categories B and C correspond to 20% (1.4 decipol) and 30% (2.5 decipol) respectively. It is interesting to compare the recommendations of this document with the values measured in the audited buildings of the European IAQ-Audit project (8). In a total of 226 rooms, the PAQ was assessed by a trained panel and the outdoor

Material number	Quantity [%]	Perceived air quality [decipol]			
		With comparison		Without comparison	
		mean	st. dev.	mean	st. dev.
1	33	3.4	1.2	8.1	3.3
	66	5.3	2.7	8.0	2.4
	100	8.6	3.5	9.4	4.9
2	25	3.9	2.7	6.5	2.1
	50	5.2	2.6	7.7	2.7
	100	7.9	2.5	7.0	2.1

Table 2 - Evaluation of PAQ for different quantities of two materials with and without comparison possibilities. Quantity is expressed in percentage of sample that was used.

Type of room	Category	Required ventilation rate		% of rooms complying with prENV draft according to:	
		[L/s.m^2]	[L/s.person]	ventilation rate	perceived IAQ
Single office room	A	2.0	20	55	9
	B	1.4	14	67	12
	C	0.8	8	78	32

Table 3 - Percentage of rooms complying with the recommendations of prENV1752 (26).
(Figures in last column assume clean outdoor air.)

air ventilation rates were determined. Table 3 presents the percentage of audited rooms which complied with the recommendations of prENV 1752. It can be seen that the ventilation rate in a majority of the rooms was higher than the minimum requirements. However, the corresponding PAQ levels were met in very few cases. No location was found below 2 decipol, and less than 3% reached category C of 2.5 decipol. Even if outdoor air was clean, only 32% of the locations would reach category C, and less than 9% would attain category A (the last column of Table 3).

This lack of low decipol levels in the audited buildings can be related to the method used. In general, levels below 2 decipol are hard to attain. There are two aspects to this. Either it is essential to improve methods for measuring low pollution levels (<2 decipol), or the pollution levels below 2 decipol are just not as critical as we think. The latter aspect indicates that the relationship between the PAQ expressed in decipol with the percentage of dissatisfied visitors needs to be studied carefully, especially at the low decipol levels. As was stated earlier, other investigations only partly confirmed the relationship shown in Figure 1, on which the olf-decipol method is based (21,22).

prENV1752 (26) categorizes values for indoor and outdoor air. The IAQ-Audit project made available average values for indoor and outdoor air. The average PAQ level indoors was 5.7 decipol with a standard deviation of 2.2 decipol. The average outdoor PAQ level was 1.9 decipol with a standard deviation of 1.2 decipol. Assuming that in at least 16% of the investigated buildings a good air quality was present (none of the buildings were known to be Sick Buildings), it can then be said that a good or excellent air quality is equal to the average minus the standard deviation (5.7 - 2.2 = 3.5 decipol). Assuming that in at least 16% of the investigated buildings a poor air quality was present, it can be said that a poor air quality is equal to the average plus the standard deviation (5.7 + 2.2 = 7.7 decipol). The same can be calculated for the outdoor air quality (excellent: 1.9 - 1.2 = 0.7; poor: 1.9 + 1.2 = 3.1).

Figures 9 and 10 show a rough comparison of values given in the prENV1752 and average values calculated from the IAQ-Audit project. As can be seen, the levels of perceived air quality as presented in the prENV1752 are much lower than the average levels found in the IAQ-Audit project. In both cases (outdoor and indoor air), the PAQs in the IAQ-Audit project which are described as A or excellent are described as C or poor in the prENV1752. It must be noted that the prENV1752 is meant for low-polluting buildings which still need to be constructed, while the IAQ-Audit data is from existing buildings.

The average perceived air quality in the 56 audited buildings was 5.7 decipol, the average outdoor level was 1.9 decipol, and the average source strength of the materials, persons, and activities was 0.4 olf/m^2 (from which 0.1 olf/m^2 was caused by occupants) (8). Assuming that outdoor air is clean and that ventilation systems do not pollute the incoming air, the average perceived air quality caused by materials, persons, and activities would then be circa 4 decipol (assuming subtraction of outdoor from indoor PAQ is correct). For a source strength of 0.2 and 0.4 olf/m^2 (the prENV1752 assumes a source strength of 0.2 olf/m^2), this would lead to a ventilation requirement of 0.5 and 1.0 L/s.m^2 or 5 and 10 L/s.person, respectively. These values are lower than the current recommended values for categories A and B (see Table 3).

Therefore, the levels given in the prENV1752 need to be adjusted to make ventilation guidelines for existing buildings. More field-data are required for that. The IAQ-Audit project comprised only 56 European office buildings, which does not represent a significant number of the total office building stock.

Trained Panels

Reference Gas

There are different ways to determine the main compounds of bioeffluents and many studies have been made to find these. A list of criteria can be set up for selecting the compound that seems most suitable as a reference instead of bioeffluents. The reference compound (2-propanone, C_3H_6O) was chosen from the

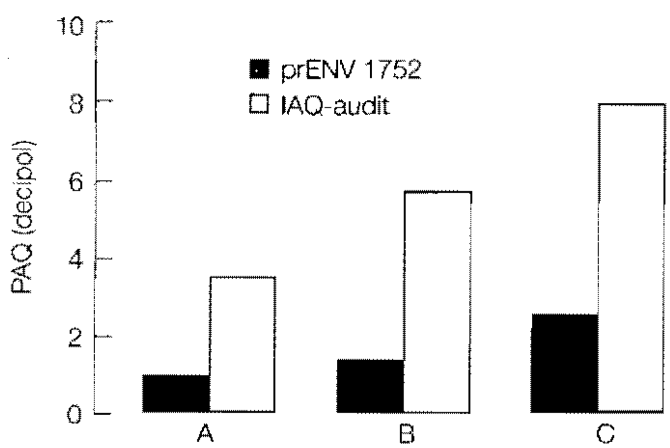

Figure 9 - Comparison between outdoor levels as given in the prENV1752 and as found in the IAQ-Audit project.

compounds that were selected through a literature study (6).

Comparing the PPF and the DPF for the IAQ-Audit panels shows that no direct relationship could be found between performance of a trained panel with respect to 2-propanone and performance of a trained panel with respect to field evaluations. The same was concluded by Groes *et al.* (27). They compared for each trained panel member the mean squared residual for 2-propanone with the mean squared residual for field evaluations. The mean squared residual was defined as the mean of the squared differences between the mean value of the whole panel and the single vote.

Although this comparison is made for trained panels and more panel data are required to make a comparison possible between untrained, half trained and trained, it might indicate that 2-propanone is not the correct reference gas to be used for training.

It is possible to select a reference in another way. An improvement would be to select several reference gases not based on human bioeffluents but based on pollutants found frequently in indoor air. For each type of pollution source (for example, activities in a building, construction materials of a building, or a ventilation system), one or more emitted gases can be selected and the relationship between the con-centration of those single gases with the perceived air quality in decipol can be determined by a large, naive panel of subjects. Even mixtures of gases may be studied in this way such as the mixture of organic compounds used by Mølhave (28). A panel can then be trained with the use of those chosen reference gases, which will relate more to the different types of air quality found in the indoor environment than 2-propanone does.

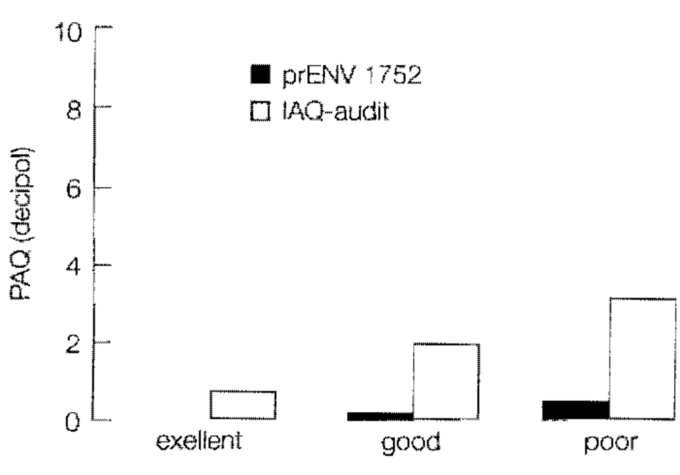

Figure 10 - Comparison between indoor levels as given in the prENV1752 and as found in the IAQ-Audit project.

Decipolmeter

A critical point in the use of the decipolmeter as an instrument to produce different PAQ levels to train a panel to evaluate PAQ is the establishment of the low values: values below one decipol. A zero-decipol level cannot be established by the decipolmeter as such. The decipolmeter without any 2-propanone results in a PAQ level of 0.8 decipol (Figure 4). Investigations to establish a zero level are necessary.

Training Procedures

The training of a panel is, so far, mainly based on the ability to evaluate different 2-propanone concentrations in decipol. The use of a description method could be a supplement: for example, the recognition of several single, standard pollution sources, which are generally found in the indoor environment, and also the recognition of mixtures of these sources. The trained panel could then not only quantify the PAQ in decipol but also identify the main pollution sources present.

A step further could be to have standard pollution sources with fixed decipol levels. Each standard has then to be evaluated by a large, naive panel. The problem with this is that it may be difficult to reach the same conditions for a particular source. Factors such as age, temperature, humidity, exposure to other pollutants, and the history of the source can all influence the source strength of a pollution source and therefore the perceived air quality level.

Further study on the development of a training procedure is recommended including developing a description method.

Performance Criteria

A new tool to calculate the performance of a panel is available with the introduction of the three new performance factors. The three performance factors IPF, PPF, and DPF seem to be independent of the PAQ level. However, the dependency on the number of evaluations still needs to be investigated. Furthermore, more panel performance data are required to define these performance factors more accurately. An important criterion is not yet considered, namely the reproducibility of a panel and/or panel member. Reproducibility can be defined as the standard deviation around the mean of several replicas of a source divided by the mean vote of that source. An additional performance factor that takes reproducibility into account could be the Reproducibility Performance Factor defined as the standard deviation around the mean divided by the allowed standard deviation around the mean.

Bluyssen (6) studied the reproducibility of trained panels. An example of the reproducibility of a trained panel is given in Table 4. The panel evaluated eight sources (other than 2-propanone) in decipolmeters each two times in random order and on two different days.

Source	Evaluation of Trained Panel		Reproducibility (R)[1]
	First [decipol]	Second [decipol]	
1	11.1	12.5	0.06
2	6.5	8.7	0.14
3	10.0	9.4	0.03
4	8.0	11.0	0.16
5	7.0	7.3	0.02
6	7.1	9.9	0.16
7	10.5	10.6	0.01
8	11.1	8.8	0.12
Average			0.09

[1] Reproducibility R is defined as the standard deviation among the two votes given to the source divided by the mean vote for that source.

Table 4 - Reproducibility of a trained panel (6).

Groes *et al.* (27) introduced a performance figure based on the average vote behavior of all IAQ-Audit panels regarding 2-propanone. They defined probability limits inside which a certain percentage of the votes given to different 2-propanone concentrations would fall. In this approach, the relationship voted=correct is ignored and a comparison is made with the average votes of the IAQ-Audit panels. Therefore, the probability limits presented are not equally distributed around the line voted=correct. Since the line voted=correct is a fact, it seems strange not to use this in a performance definition.

*The **BULLETIN** invited Building Research Establishment (BRE) researchers, Ole Fanger, and Henrik Knudsen to respond to this article. The article authors then submitted a response to the BRE's and Fanger's comments, and the BRE submitted a follow-up response. All of these contributions follow and are quite interesting — read on.*

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Index List

A = tangent of angle difference between lines
B = intersection with Y-axis
C_i = perceived indoor air quality, desired [decipol]
C_o = perceived outdoor air quality [decipol]
correct = correct PAQ level [decipol]
DPF = Deviation Performance Factor
ε_v = ventilation effectiveness
G = total pollution load [olf]
IPF = Individual Performance Factor
n = number of panel members
PAQ = Perceived Air Quality
PPF = Panel Performance Factor
Q = ventilation rate required [L/s]
σ = standard deviation
σ_x = standard error = $\sigma/\sqrt{n}$
voted = voted PAQ level [decipol]
R = reproducibility
s = estimated standard deviation
$t_{.975}$ = distribution for 95% confidence interval
μ = mean
x = estimated mean

Responses

Comments by the Building Research Establishment

The following comments on "The Decipol Method: A Review" were submitted by Claire E Aizlewood, Nigel A. Oseland, and Gary J. Raw of the Building Research Establishment, Watford, England.

The authors have produced an interesting review of the decipol method. It provides a useful update on some of the work that has been done using the decipol method, and covers many aspects of the subject. However, the review is not complete and there are three additional important points that should be made: (a) the method can be costly and impractical, (b) its use in the European IAQ Audit project showed clearly that the method cannot be used to predict occupants' building-related symptoms or their evaluation of environmental conditions, and (c) the use of the decipol method could cause problems if used to set ventilation rates.

Our comments are split into sections, each dealing with one of the major subject areas covered by the paper. There is not sufficient space to comment on all aspects of this paper, or to deal in detail with every specific point. BRE has previously provided comments and criticism on the theory, the derivation of the olf and decipol units, and the practicality of the method [1, 2]. Because of limited space, these comments will not be repeated here in any detail.

The Olf and Decipol Methodology

Bluyssen *et al.*'s Figure 1 shows the relationship established between olfs and percentage dissatisfied. It is possible that this relationship is the root of many of the problems associated with the olf and decipol methodology. The lack of reliability of the relationship would be more obvious if the graph included the original data points, with confidence limits and correlation coefficient. Simply presenting the regression line is misleading, as it suggests a confidence in the line which is not justified. The relationship shown in Figure 1 should be redefined, using a more robust method.

The additivity (or non-additivity) of olfs is an area of concern raised by the authors. The evidence shows that olfs cannot simply be added. As the authors state later, it is not valid to subtract outdoor PAQ from indoor PAQ, so the calculations of olf load are not valid. This means that adding olfs when considering pollution loads, decipol votes and ventilation rates is not appropriate.

Sensory Panel Procedure and Performance Factors

The choice of reference gas for sensory panel training has been a concern since the beginning of the work. Most people involved with training sensory panels agree that 2-propanone is not the best choice but producing a suitable alternative has proved difficult. The replacement gas or gases must be non-toxic, preferably non-flammable, representative of pollutants found in buildings, should preferably have no very distinctive qualities, and must be easily reproduced. We agree with the authors that if such a reference gas could be developed, the relationship between sensory panel performance in the laboratory and performance in the field could be very much improved. It is important to remember that this addresses only the reliability and not the validity of the method.

The performance factors described in the review have advantages and disadvantages. The main advantage is that a reliable performance factor permits comparison between panels and between panel members. The main disadvantage is that, if the performance factor is not defined correctly, important information about performance is lost. It seems sensible to compare panel performance to the "correct decipol" line, rather than to average panel ratings, but it must also be remembered that this line is not necessarily a "fact"; it is a regression line through average panel ratings. BRE also found that panel assessments of different amounts of the same material (without comparison to other samples) do not show the expected increase in decipol vote with quantity of material. The panel assessed many different quantities of the same material. There was very little difference in assessments made of the different quantities, except for very low quantities.

The authors spend some time comparing the performance of trained and untrained panels. Is the debate between untrained and trained panels of any value if neither panel's assessment represent either environmental conditions or occupant assessments? One way of looking at it is to say that the performance of the naive panels has no potential for improvement, whereas a trained panel have considerable potential to improve, through changes to the sensory procedure.

Application of Decipol Votes and the "Comfort Equation"

The decipol was originally presented as a method of representing occupant responses, and calculating required ventilation rates. The European IAQ audit project demonstrated no relationship between the decipol and occupant response and only a very poor relationship with fresh air flow rates.

It is clear that the decipol vote is the immediate assessment of a visiting panel, rather than a response over time. The assertion that the decipol takes into account irritant pollutants as well as odorants is doubtful, as most irritants take some time to produce a reaction. The occupants' assessment of air quality will be different to the panel's because (a) they are adapted to the air and odours, and may not even notice a smell which seems strong to the panel, and (b) they have been exposed to irritants for long enough to perceive effects. Since the evidence shows that the unadapted (panel) rating is not proportional to the adapted (occupant) rating, it is inappropriate to use the panel votes to predict occupant response. The method may be useful for predicting how visitors to a building would respond to the air quality on arrival, but this is a very limited application.

It should be noted that the olf and decipol method was submitted to the European Standards Committee CEN TC156 for formal vote on its inclusion as an informative annex to the draft pre-standard prENV 1752; the method was not proposed to be part of the standard. Even this informative publication of the method was rejected.

Conclusions

The "new comfort equation for air quality" is not valid, and should not be used. It is not merely an incomplete method: it produces non-useful information. Indeed there must be concerns that its use could increase indoor climate problems, directly by increasing draughts or reducing humidity, or indirectly by diverting resources from more effective approaches to improving the indoor environment.

Now that some of the key problems with the decipol method and training procedure have been identified and acknowledged, we have the opportunity to build on it, to work towards a better method. Such a method would need to be more robust and practical, and to be a valid proxy for occupant assessment.

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Comments by Ole Fanger *et al.*

The following comments on "The Decipol Method: A Review" were submitted by P. O. Fanger and P. Wargocki, of the Technical University of Denmark and H. N. Knudsen of the Danish Building Research Institute.

When discussing whether to use a trained panel or untrained panel it is not enough to consider only the accuracy of the assessments of the two types of panels. Equally, or even more important, is whether the mean assessments are correct. In general, trained panels using 2-propanone as a reference gas have a tendency to vote too high at low pollution levels and too low at high levels. This has been documented in several studies for assessments of known levels of 2-propanone. In the European Audit study virtually no levels below 2 dp were measured either indoors or outdoors. In its present form the method using a trained panel based on 2-propanone as a reference gas is rather unsuitable for many field studies, where low air pollution levels are expected to occur.

We have therefore reverted for some time now to the classical method of asking subjects directly about acceptability. This more direct method was used in the original studies with bioeffluents (2,3,4,5) and in numerous laboratory and field studies (6,10). This method with untrained panels has also been included in ASHRAE Standard 62 "Ventilation for Acceptable Indoor Air Quality for 15 years. ASHRAE Standard 62 recommends 20 untrained observers as the minimum size of a panel. Considering that the size of an untrained panel is a balance between accuracy, economy and practical aspects of experiments, a panel of minimum 40 subjects has been selected for sensory assessments in the currently running European Database project on Indoor Air Pollution Sources, as a reasonable compromise. In some studies we are at present using both the classical method and the 2-propanone method in an effort to establish a transfer function from which previous 2-propanone-based studies may be corrected. We are also studying potential alternative reference gases (containing mixtures of indoor air organic pollutants) which may resemble common IAQ better than 2-propanone.

As a reference, 2-propanone has nothing to do with the definition of olf and decipol units. One olf is the sensory pollution load caused by a standard person. In climate chambers or experimental auditoria in North America, Europe and Japan, the acceptability of bioeffluents has been studied in detail. As shown in Fig. 1, the agreement is striking. A standard person may therefore be regarded as a typical sedentary adult person living in the developed world in the 1980s and 1990s.

Since we already have a large database on bioeffluents from three continents at levels corresponding to up to 40% dissatisfied, we see no urgent need for further bioeffluent studies now. But supplementary studies at very high bioeffluent concentrations would of course be useful in future. However, many studies have already shown that the building is usually a more important pollution source than people. Our primary target should therefore rather be building materials and HVAC systems; numerous studies are fortunately already in progress in this area, e.g. as part of the European Database on Indoor Air Pollution Sources.

As regards the addition of pollution sources, Fig. 2 compares the results of simple addition of pollution sources with measured data. Lauridsen (6) and Iwashita (7) studies the addition of building materials, bioeffluents and ETS using large panels trained with the 2-propanone reference. The data in Fig. 2 indicate that the addition of sources in general is a first reasonable approximation. Whether addition applies to all types of source has still to be seen, and should be further investigated. Addition of sources should not be confused with addition of effects on human beings. It is well known that the perception of human beings is not proportional to the source strength of light, noise or pollution and the perceptions are not additive.

Your observations concerning the limitations of the simple steady-state comfort equation are certainly correct. Source strength may not be constant but may vary with temperature, humidity, concentration, age, etc. We all know that sorption and desorption occur and conditions in practice are usually transient, not steady-state. But we are continually learning more from current research so that we can gradually improve the model.

For the prediction of IAQ we are probably at present at the stage where thermal models were 50 years ago: Temperatures were predicted based on a simple steady-state model and rough estimates of cooling and heating loads, without considering thermal storage. But at least this simple IAQ comfort equation is a modest beginning to a rational prediction of perceived IAQ at the design stage of a building, as we have rational tools to predict perceived thermal and acoustic conditions.

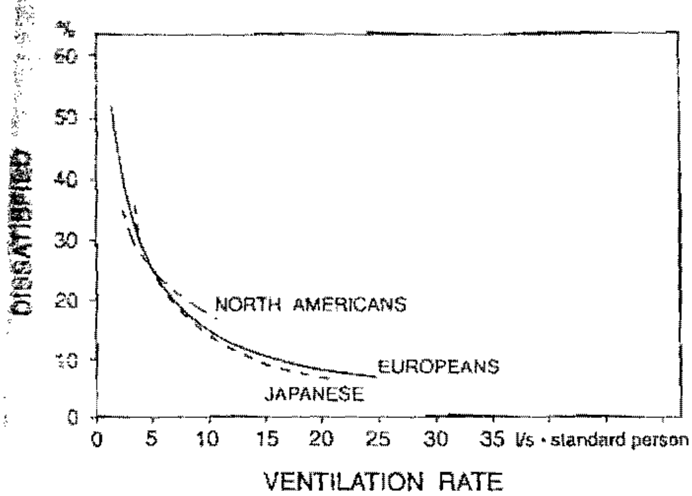

Figure 1 - Percentage of dissatisfied visitors as a function of the ventilation rate, when human bioeffluents are the exclusive pollutants. Data from the European (2, 3), North American (4), and Japanese (5) studies.

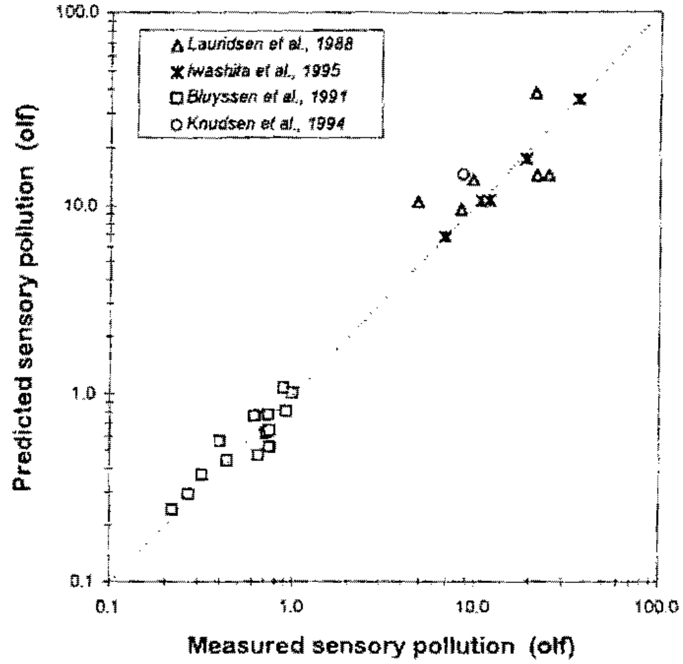

Figure 2 - Relation between measured and predicted sensory pollution of the air polluted with bioeffluents, tobacco smoke and materials in climate chambers (6, 7) and with mixtures of materials in small glass chambers (8, 9). The dotted line is the identity line of measured and predicted sensory pollution.

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The Authors Respond

The following comments were submitted by the authors of "The Decipol Method: A Review" in response to the previous submissions from Fanger et al. and the Building Research Establishment.

Comments re: Fanger *et al.*

Trained and Untrained Panels

The use of untrained panels is a step backwards. As was shown in the article, many more untrained panel members are required than trained panel members to reach a similar accuracy. Furthermore, the practical implementations of using untrained panel members is enormous, because of their large numbers. Originally that was the reason for the development of a training procedure: to reduce the number of persons required. The method recommended by ASHRAE using only 20 untrained persons is obviously not a very accurate one. In fact, are their any reports of people using that method?

Of course, not only the accuracy of the assessments but also the mean assessment is important. Both are included in the individual and panel performance factor. An IPF or PPF value of zero means that the assessment is equal to the correct level. This, however, can only be said for the performance factors related to 2-propanone. So far, no correct perceived air quality levels are available for pollution sources other than 2-propanone. Maybe the Database Project will provide these data and then a performance factor including the correct and voted level for pollution sources other than 2-propanone can be defined as well.

The use of trained panels can be improved by introducing reference gases which are much closer to the smell of materials. Whether these reference gases will be expressed in decipol or some kind of other unit is not important, but the fact remains that a smaller panel of trained persons is much more practical and accurate than a large panel of untrained persons. Furthermore, as pointed out in the comments of the BRE, the performance of a trained panel can be improved by careful selection and training; the performance of an untrained panel can, however, only be improved by increasing the number of noses.

Basis of Method

Groes (*) performed a statistical analysis on all 2-propanone evaluations of eight panels in the IAQ-Audit project (3,584 votes from more than 100 persons). Both linear and power regression resulted in a line almost identical to the voted=correct line. Based on this analysis, it was concluded that no systematic error is present. Only in the very low concentrations (<2 decipol) would calibration have an effect. The reason for this can be found in the training environment. As was stated in the article, levels below 2 decipol are hard to reach and the decipolmeter itself already reads approximately 1 decipol. Panel members are therefore not well trained in levels below 2 decipol. Remembering the fact that the 2-propanone/decipol relation is established using the "classical" method of untrained panel members, it could very well be that the low levels in the original olf/decipol curve (Figure 1) are wrong and consequently the low levels of the 2-propanone/decipol curve as well. Considering the Yugoslavian data (**), this is a possibility.

To state that we should forget about bioeffluents is a very dangerous one, since the definition of olf and decipol is based on that. Should we also forget about olf and decipol? The emissions of materials are definitely different from bioeffluents.

Comments re: the BRE

Costs and Practice

The decipol method can indeed be costly and impractical. However, another method than using panels of people to measure the perceived indoor air quality does not exist at this point in time. Several institutes and companies are trying to develop an artificial nose, but so far without success. Furthermore, the use of a trained panel has introduced an approach that is easier to handle in practice than the use of an untrained panel.

Occupant Responses and Sensory Panel Evaluations

In the IAQ-Audit project, the occupants' acceptability rating and number of building-related symptoms did not show statistically significant correlation with perceived air quality in the offices evaluated by the sensory panel. It could be discussed whether a relation was to be expected. It is important to remember that the occupants and the sensory panel did not evaluate the same air. The perceived air quality was measured by a trained sensory panel at only five locations in a building with approximately 200 to 500 occupants, whereas the occupants evaluated the air quality in their own office rooms. The sensory panel gave the initial impression of the air quality as opposed to the occupants who gave the adapted perception. Furthermore, the panel is only concentrated on the sensory evaluation of air, while the occupants are prone to many different sensations.

The use of a trained panel was demonstrated in the IAQ-Audit project. The assessments of a trained panel are a measure of the possible dissatisfaction of visitors or the first impression of indoor air quality. Since Yaglou, existing ventilation standards (e.g. ASHRAE, CIBSE, Scandinavian) have been based on the first impression of indoor air quality. This first impression may be different from the adapted impression of occupants, as is clearly shown in the IAQ-Audit project. This doesn't mean that the first impression is not important. The first impression of indoor air quality is important in its own right, like the first impression of any other parameter can be essential. The unadapted first impression is the basis on which ventilation systems have been designed for 60 years. The adapted impression of the occupants is gradually also being considered important.

Ventilation Rates

As was said for a long time, existing ventilation standards are based on the first impression of indoor air quality. Nevertheless, it was not always used, mostly because it was assumed that there are no other pollution sources present in a building than occupants. In a clean building, i.e. a building with only one pollution source, the occupant, the decipol method would not be required. But in a building with many other sources the decipol method can be of use to detect, identify, reduce and perhaps eliminate these sources. The IAQ-Audit project found that the perceived air quality assessed by the sensory panels was on the average slightly better in buildings that had a higher outdoor airflow rate. However, it was shown that in some cases the ventilation measurements resulted in airflow rates with large uncertainties. Furthermore, the quality of the supply air was not taken into account and pollution sources present in the ventilation systems make a comparison between perceived air quality indoors and the outdoor airflow rate difficult or even invalid.

Concluding Remark

In the IAQ-Audit project, for the first time sensory panels were trained in nine different countries using a predescribed method. This method can be improved and development is necessary. However, it was shown that sensory panels can be used to screen buildings for combined source-ventilation problems. The trained sensory panels are therefore yet another instrument to describe indoor air quality and sources of pollution in buildings.

References

* L. Groes, The European IAQ-Audit project, A statistical analysis of indoor environmental factors, Ph.D. thesis, Laboratory of Heating and Air Conditioning, Technical University of Denmark, November 1995.

** Ref. 22 in article.

Responses

The BRE Responds to the Authors' Comments

The following comments were submitted by Claire E Aizlewood, Nigel A Oseland, and Gary J Raw in response to the comments by the authors of "The Decipol Method: A Review."

Costs and Practice

We agree that a trained panel is easier to handle in the field than an untrained panel. Also, the cost and difficulty in using a trained panel would be more worthwhile if the results were more useful. If the method is improved, and the usefulness of the results is therefore improved, then the practical difficulties would be easier to justify. The advantage of the untrained panel is that it uses just percentage dissatisfied, without using the olf and decipol. This minimises the errors caused by the uncertainty in the definition of the olf and decipol. Currently, the most reliable method for measuring perceived air quality in offices is using a questionnaire to ascertain occupant perception.

Occupant Response and Sensory Panel Evaluation

We agree with the differences between sensory panel and occupant evaluations - these are all comments we have made previously. But these differences should not be treated as excuses for a lack of correlation between decipol votes and occupant votes - they represent a fundamental problem with the method. The decipol votes do not correlate with occupants' responses on acceptability, indoor air quality, odour, stuffiness, or any of the other related variables. One of the original stated aims of the decipol was to represent occupant response, so perhaps we should be aiming to refine the method until it does represent the occupants' perceptions.

The olf and decipol methodology, and the sensory procedure, were developed as an attempt to improve the existing ventilation standards (based on Yaglou). The existing methods and the sensory procedure are both based on first impressions, but neither of them are adequately representing occupants' perceptions. Immediate impressions of air quality are important, but so are adapted impressions. An adapted impression will take into account irritants that are present, and is also more relevant to occupant health. So should we be focussing our energies on developing a method which uses both adapted and unadapted evaluations? It is still difficult to see how the decipol can represent both odour and irritation.

Ventilation Rates

We believe that there is potentially a role for the sensory procedure in the assessment of building materials, furnishings, and other possible pollution sources, either in the laboratory, or perhaps in specific cases of "trouble-shooting" in offices. However, until it has been demonstrated to provide consistent and reliable results, it should not be used in the setting of ventilation rates for buildings. Even if the existing standards are not perfect, there is no justification for replacing them, unless the replacement represents a significant improvement. The European IAQ Audit project was fairly conclusive evidence against the reliability of the olf and decipol methodology.

Concluding Remark

The sensory procedure is a method which provides additional information about office air quality. This information may be interesting when used in combination with traditional methods, such as occupant questionnaires and physical measurements. However, at this stage, it is not a method with any immediate relevance to occupant health or comfort, or ventilation rates.

Publications

ASTM Issues CO_2 Guide

Andy Persily has prepared yet another paper on CO_2 measurements and their valid use in building assessments. ASTM has adopted this one as a provisional standard and, hopefully, its publication will lead to far fewer abuses of CO_2 data. The recently published title is ASTM PS40 Provisional Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation.

Building operators and investigators can use carbon dioxide effectively to evaluate various aspects of ventilation system performance and the adequacy of air exchange in relation to occupant-generated contaminants. Since carbon dioxide is one of the easiest indoor air pollutants to measure, its measurement is a potentially important tool.

However, CO_2 measurements must be used correctly. There is widespread misuse of CO_2 measurements for evaluating IAQ and ventilation. The most common error is assuming that a CO_2 measurement reading taken in a space is a direct indication of the outside air ventilation rate. This often results from misinterpreting the ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality. The ASHRAE standard uses the relationship between steady state CO_2 concentrations and human occupant CO_2 generation rates to establish a link between ventilation and occupant density. In Appendix D of the standard, the relationships are described, but not very clearly.

The link is based on several assumptions that are often inappropriate. These assumptions include a 350 ppm outdoor CO_2 concentration, a steady state CO_2 concentration indoors, accurate measurements, and other conditions. Many practitioners claim that measurements below 1000 ppm demonstrate compliance with the ASHRAE standard. This is simply not true. CO_2 can only be used as a surrogate for bioeffluents, and then only with considerable caution. CO_2 cannot be a surrogate for pollutants from other sources. That said, measurements of 650 ppm CO_2 above outdoor concentrations do indicate probable non-compliance with the minimum ventilation rate of 15 cfm/p. There is no presumption of health effects at this concentration.

Building materials, appliances, equipment, and occupant activities are important sources of contaminants that can make indoor air unpleasant or even unhealthful. Outdoor air and soil gas can also be important contaminant sources. Carbon dioxide concentrations can give little or no indication of the quality or acceptability of the indoor air with respect to contaminants from these other sources.

CO_2 misuse is exacerbated by the practice of some overzealous manufacturers whose misleading literature overstates the effectiveness of CO_2 levels as IAQ indicators. It has also been common for manufacturers to fail to stress the importance of proper calibration of their CO_2 measuring instruments. Yet our experience suggests this is absolutely indispensable, particularly with the most widely distributed device. Finally, some vendors describe oversimplified CO_2-based measurement procedures.

Inaccurate measurements are common due to instrument problems including improper or no calibration, drift, interference, temperature differences between measurements that are compared without correction, and a lack of the requisite sensitivity for the measurement.

The Guide's Approach

PS40 describes the use of CO_2 concentrations to indicate the acceptability of a space in terms of human body odor. Among the many connections that have been implied between indoor CO_2 and IAQ, the relationship of CO_2 and body odor is the only one that has been well-established in laboratory and field experiments. The provisional guide also describes the following uses of indoor carbon dioxide concentrations to evaluate building ventilation: mass balance analysis to determine the percent outdoor air intake at an air handler; the tracer gas decay technique to estimate whole building air change rates; and, the constant injection tracer gas technique at equilibrium to estimate whole building air change rates. PS40 also discusses how continuous monitoring of indoor carbon dioxide concentrations can be used to evaluate building ventilation and IAQ. Finally, the provisional guide discusses a number of issues related to concentration measurement such as sampling locations and the need for field calibration. However, it does not include or recommend a method for measuring carbon dioxide concentrations. In addition, it does not address the use of indoor carbon dioxide to control outdoor air intake rates.

This guide has been promulgated as a provisional standard, a means by which standards can be adopted more rapidly within ASTM. PS40 will remain "on the books" for two years, during which time Subcommittee D22.05 on Indoor Air will work to approve the guide as a full consensus standard. Comments on the standard can be directed to Andy Persily at NIST at 301 975 6418, fax 301 990 4192, and email apersily@nist.gov or to George Luciw at ASTM, 610 832 9710, email gluciw@local.astm.org.

ASTM Subcommittee D22.05 on Indoor Air will discuss the guide at its next meeting held April 16-17 in Orlando, Florida. Contact George Luciw for more information. Copies of the standard can be purchased from ASTM, tel. 610 832 9500.

Calendar of IAQ Events

April 16-18, 1996. **ASTM Subcommittee D22.05 on Indoor Air, Spring Meeting**, Omni Rosen Hotel, Orlando, Florida. Contact: George Luciw, ASTM Staff Manager, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, 610 832 9710, Fax 610 832 9666. *The subcommittee will be considering results of ballots on placement and use of passive monitors, inspection of water systems and investigating possible outbreaks of Legionellosis, test method for nicotine in indoor air, and estimating contribution of environmental tobacco smoke to respirable suspended particles based on UVPM and FPM. There will be a workshop on Carbon Monoxide detectors organized by Niren Nagda (301 540 1300, Fax 301 540 6924). There is no charge for attendance at the meeting and membership is not required to participate.*

April 22-23, 1996. **Diagnosing and Mitigating Indoor Air Quality Problems**, San Francisco. Sponsored by Indoor Environmental Engineering (IEE). Contact: IEE, 1448 Pine Street, Suite 103, San Francisco, CA 94109, 415 567 7700, Fax 415 567 7763. *Instructor is Francis J. "Bud" Offermann PE, CIH. Course fee is $795 ($695 for ASHRAE, ABIH, AIHA, and BOMA members).*

April 29-30, 1996. **IAQ Diagnostics Hands-On Assessment of Building Ventilation & Pollutants Transport; Microorganisms in Indoor Air: Assessment and Evaluation of Health Effects & Probable Causes**, Honolulu, Hawaii. Sponsored by EPA Region 9 and Building Owners and Managers Association Hawaii. Contact: University of Tulsa, Chemical Engineering Dept., 600 S. College Avenue, Tulsa, OK 74104, 918 631 3046, Fax 918 631 3268. *Two one-day courses; fee $350 for both courses, $225 each taken separately. Faculty for Microorganisms includes internationally renowned Harriet Burge of Harvard School of Public Health.*

May 18-24, 1996. **American Industrial Hygiene Conference & Exposition**, Washington Convention Center, Washington, DC. Cosponsored by American Industrial Hygiene Association (AIHA) and American Conference of Governmental Industrial Hygienists (ACGIH). Contact: AIHCE Registration Coordinator, PO Box 4088, Frederick, MD 21705. *This is the major industrial hygiene event in the US including an extensive program, professional development courses, employment opportunities, meetings, tours, etc., and a giant exhibition of industrial hygiene and safety equipment, consultants, and government agencies. Registration fee depends on membership and timing; early registration discounts until April 24.*

June 22-26, 1996. **ASHRAE Annual Meeting**, San Antonio, Texas. Contact: ASHRAE Meetings Department, 1791 Tullie Circle NE, Atlanta, GA 30329, 404 636 8400, Fax 404 321 5478.

July 7-11, 1996. **Indoor Air Quality: Critical Evaluation of the Science and the Art**, Johnson State College, Johnson, Vermont, sponsored by ASTM. Contact George Luciw, ASTM Staff Manager, 610 832 9710.

July 23-26, 1996. **Indoor Air Quality/HVAC Diagnostics and Mitigation Training Course**, Harrison, Maine, The H. L. Turner Group, Inc. Contact: The Turner Group, RR#1, Box 535A, Harrison, Maine. 207 583 4571, Fax 207 583 4572. *Tuition is $1095; the faculty is high quality.*

December 8-11, 1996. **Risk Assessment and Risk Management: Partnerships Through Interdisciplinary Initiatives**, Fairmont Hotel, New Orleans, Louisiana. Sponsored jointly by International Society for Risk Analysis and International Society for Exposure Assessment. Contact: Society for Risk Analysis, 1313 Dolley Madison Blvd., Suite 402, McLean, VA 22101, 703 790 1745. *A Call for Papers, Symposia, and Workshops has been issued. Deadline for submission is May 31, 1996. Send Abstracts of one paragraph (not less than 150 words) on the proper form, symposia, and workshop proposals to Conferences and Workshops Committee, SRA Secretariat, at the above address. Exhibitors contact Lori Strong or Sue Burk at 703 790 1745, Fax 703 790 2672. Competitive awards of $500 each will be granted to up to six students with the highest-quality papers.*

International Events

April 21-24, 1996. **Buildings for Healthy Living**, Czech Republic International Conference, Praha Hotel, Prague, Czech Republic. Contact: Dr. Ivana Holcátová, Institute of Hygiene & Epidemiology, 1st Faculty of Medicine, Charles University, Studnickova 7, 128 00 Prague 2, Czech Republic. *The official language of the conference is English. Registration fee is US$400 ($350 for ISIAQ members). There are several post-conference tours available in and around Prague.*

July 17-19, 1996. **Roomvent '96, The 5th International Conference on Air Distribution in Rooms**, Yokohama, Japan. Contact: Dr. S. Kato, Murakami and Kato Laboratory, Institute of Industrial Science, University of Tokyo, 7-22-1 Ropponi, Minato-ku, Tokyo 106, Japan, +81 3 3402 6231 ext 2575, Fax +81 3 3746 1449.

July 21-26,1996. **Indoor Air '96, The 7th International Conference on Indoor Air Quality and Climate**, Nagoya, Japan. Contact: Dr. Koichi Ikeda, Secretary, Indoor Air '96, The Institute of Public Health, 6-1, Shirokanedai 4-chome, Minato-ku, Tokyo 108, Japan, +81 3 3441 7111 ext 275, Fax +81 3 3446 4723. *This is the largest and most important international indoor air conference, held every three years. It should be particularly interesting with a large amount of information from the Asian indoor environment research community. Organizers indicate that a very large number of abstracts have been received, and the paper due date has now passed. Concerns about high costs for travel to Japan appear contradicted by the conference announcement showing living expenses in Nagoya not much different from those found in most European and North American major cities.*

August 17-21, 1996. **Environmental Exposures, Risks and Values: Setting Priorities in Epidemiology**, International Society for Environmental Exposure (ISEE), University of Alberta, Edmonton, Alberta, Canada. Contact Dr. Colin L. Soskoine, Epidemiology Program, Univ. of Alberta, 13-103 Clinical Sciences Building, Edmonton, Alberta, Canada. T6G 2G3, 403 492 6013, Fax 403 492 0364. *Contact Dr. Soskoine to receive the Announcement.*

August 25-30, 1996. **3rd NIVA Course on The Sick Building Syndrome**, Schæffergården. Charlottenlund (Copenhagen), Denmark. Contact: Gunilla Ahlberg, Course Secretary, NIVA, Topeliuksenkatu 41 a A, FIN-00250 Helsinki, Finland, +358 0 474 7498, Fax +358 0 474 7497. *Course fee is FIM 2000 and participation is limited to 40 students. This has been one of the most outstanding indoor air programs in the past due to a large number of expert faculty members and a great deal of discussion among faculty and between faculty and students. The conference center is also one of the finest. Some scholarships are available.*

September, 1997, **Healthy Buildings '97**, Washington, DC. Organized by ISIAQ, ASHRAE, and CIB. *Watch for First Announcement and Call for Papers in the next **BULLETIN**, or contact: Nadia Boschi, Virginia Tech, 703 698 4701, Fax 703 698 6062.*

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