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Decipols: Should We Use Them?

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Indoor air quality
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Abstract
This paper provides a discussion on the use of the olf and the decipol. The validity of using these units to determine ventilation rates and compare pollution emission rates is discussed, in relation to their derivation and theoretical basis, and the method of application. A procedure has been developed for testing buildings by using a trained panel of people to rate air quality directly in decipol units. This was used in nine European countries as part of the 'European Audit Project'. The practical limitations of this procedure, and the implications of the results obtained, are discussed in this paper.

Introduction

Background

The idea of using people to assess indoor air quality is sensible; there is no other way of making an integrated assessment of indoor air quality as it is perceived by people. The nose is capable of detecting some chemicals at concentrations too low to measure, and smells can also evoke strong emotional reactions or memories. The sense of smell is therefore a powerful and versatile tool, but it cannot at present be precisely measured or fully explained. The challenge is to establish procedures to quantify indoor air quality in a valid and reliable manner using subjective assessment.

Fanger [1, 2] has described two proposed units for the subjective assessment of air quality, the olf (strength of pollution source) and the decipol (perceived air pollution). From these units, an equation was derived to estimate the ventilation rate required for comfort. In order to use this equation, the perceived pollutant levels (decipol) and pollution source strength (olf) need to be known. A European Concerted Action report [3] provides tables for ascertaining the values of variables required to calculate the ventilation rate. The tables provide the approximate pollution loads for buildings, occupants and tobacco smoking.

An alternative to using the tables is to train people to rate the air pollution directly in decipols by 'calibrating' their responses with a substance of known decipol value. A procedure has been developed [4] whereby groups of people are trained in this way using 2-propanone (acetone) vapour as a reference gas. This method was developed further by participants from 11 European countries to train panels to test buildings, in combination with physical measurements and occupant questionnaires [5]. This paper summarises an earlier critique of the method [6] and discusses some limitations identified in the wider European project. The paper is based partly on results from the European Audit Project, and partly on more recent work by Building Research Establisment (BRE) and others.

Aim

This paper provides a discussion on the use of the olf and the decipol. The validity of using these units to determine ventilation rates and compare pollution emission

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rates is discussed, in relation to their derivation and theoretical basis, and the method of application.

Theoretical Limitations on the Use of Decipols

The Derivation of the Equation. By definition the relationship between the decipol and the olf is linear. Thus, 1 decipol is the pollution from 1 olf ventilated at 10 litres/s (or 2 olf at 20 litres/s), so 2 decipol is the pollution from 2 olf at 10 litres/s (or 1 olf at 5 litres/s). However, it is not assumed that 2 decipol is perceived to be twice as much air pollution as 1 decipol even though it is twice the 'perceived air pollution'. Indeed, the evidence is that the relationship between a perceptual measure of a chemical substance and its concentration is not linear. According to the psychophysical power law (also known as Stevens' Law), the relationship between perceived odour intensity, I, and concentration, C, follows a power function, $I = kC^n$. For the sense of smell, the exponent n is less than 1, so a percentage change in concentration causes a smaller percentage change in perceived magnitude.

The implication is that the decipol scale would be one of varying intervals, i.e. one decipol is not necessarily the same as another in its incremental impact on perceived air quality. It can be argued that this is not in itself a problem since, for example, perceived noise level is not linearly related to sound pressure level measured in pascals. The difference is that, in the case of noise, the human response can be related to an objectively measured exposure, which depends on a source strength which can also be objectively measured. In the case of decipols, neither the source strength nor the exposure is objectively measured. The exposure is subjectively assessed and the source strength calculated from the exposure.

The decipol is of little value as a quantitative measure unless the characteristics of its non-linear relationship with human response can be defined. Unfortunately, the evidence is that the parameters of the relationship vary with substance [7] and therefore information would be needed on the substances present in each environment which is to be assessed.

Limits on Precision. Using trained panels is one method of assessing indoor air quality. Bluyssen [4] reported the performance of a panel of 14 in estimating the decipol values of the samples of 2-propanone. She found that the standard error of the panel votes was 0.6 decipol, but at the 90% ($Z = 1.65$) confidence limit a standard error ($Z = 1$) of 0.6 decipol becomes an error of $\pm$ 1 decipol (i.e. 0.6×1.65). In a later paper [8], the standard error of votes of 8 panel members had improved to 4.5% dissatisfaction, i.e. a range of 12.6–27.4% dissatisfaction for 1.4 decipol at the 90% confidence limit. The standard error of 0.6 decipol relates to a mean panel error of 1.5 decipol.

Bluyssen and Fanger [8] also illustrated that the regression line between the reported decipol level and correct decipol level has an intercept of 1.3 decipol. This constant error, possibly due to the olf value of the training facilities, needs to be accounted for, particularly when assessing buildings that meet the ventilation standards (i.e. 20% dissatisfied, said to be achieved at 1.4 decipol).

Other Problems. Oseland and Raw [6] have discussed the above and other criticisms of the development of the decipol methodology. For example, the olfload of the test chamber used in the development studies was unknown (it would not have been olf-free), the ventilation effectiveness was not measured, food and cosmetics were overlooked, and assessments were made of ambient indoor air quality, rather than air quality local to occupants. Misinterpreting the results of this method may lead to unnecessarily increased ventilation rates and consequently to higher energy consumption. The issue of training procedures has also been discussed at length in a recent paper [9].

These arguments are not rehearsed in detail here; rather the main analysis is concerned with the practical limitations of the technique, and the initial results from using it. This analysis is derived to some extent from the 'European Audit Project' and this project is therefore briefly described.

Materials and Method

The method used in the 'European Audit Project to optimize indoor air quality and energy consumption in office buildings', referred to here as the 'European Audit Project', is described in detail in the research manual [5].

Nine countries carried out surveys on office buildings, with a total of 56 buildings being audited as part of the project. In each building, occupant questionnaires on health and comfort were completed, physical measurements were made of indoor climate and indoor air quality, ventilation rates were measured, and trained sensory panels were used to make judgements on perceived air quality. The project produced a huge database, analysis of which has been reported in the international report of the project [10] and elsewhere [11–16].

In the questionnaire, occupants were asked to rate, among other things, indoor air acceptability, air odour, and stuffiness of their offices. They were also asked a series of questions about their health, in order to obtain a building symptom index (BSI) for each building. The BSI represents the average number of building-related symptoms experienced by the occupants of the building.

Further details of the method are given below in the context of problems with the method.

Results and Discussion

Practical Limitations for Applying the Decipol Method

Introduction. There were many practical difficulties associated with applying specific aspects of this method. The procedure also involved a great deal of expense, and was very time-consuming. This section is included to illustrate how impractical this procedure would be if it were to be adopted generally. Details are given about the equipment required, the problems with the method, and the difficulties of the audit procedure. Solutions or alternative methods are suggested wherever possible.

Odour Test Facility. Considerable expense was involved in setting up the training facility. The equipment needed to train the panel included a gas analyser suitable for measuring 2-propanone, reference 2-propanone gas for calibration, plus 16 decipolmeters (large glass jars, glass cones and steel support stands, miniature fans, and small glass sample jars).

The training had to be carried out in a room which has a very low level of air pollutants. The BRE facility was created from a pair of existing rooms. The walls and doors of one room (the training room itself) were completely covered in aluminium faced cladding, sealed with aluminium tape. The floor was stainless steel. The windows were double glazed, and sealed with aluminium tape. The waiting room adjoining the training room was stripped, repainted with odour-free paint, the window was double glazed, and a low-odour floor covering was fitted. An air lock was built between the waiting room and the training room to restrict air and odour migration between the two rooms.

In the training room, the ventilation rate needed was very high, requiring a large ventilation unit. The unit incorporated a particle filter and a carbon filter to reduce the ingress of gaseous pollutants. The training room was maintained at a slightly positive pressure, which minimised air infiltration. The steel benches and frames for the decipolmeters needed to be specially made.

The decipolmeters were very sensitive to small changes in local temperature and air movement, and to small movements of the jars. This meant that the 2-propanone concentrations changed slightly, and needed frequent recalibrating. The 2-propanone concentrations were obtained by placing small lidded glass jars, containing 2-propanone, at the bottom of the large glass jars. The number of small jars, and the diameter of hole in their lids, determined the concentration of 2-propanone coming out of the decipolmeter. The 2-propanone concentrations changed with very slight variations in temperature or equipment. Even moving the small jars slightly within the large jar would change the concentration considerably. The suggested method of calibrating beforehand, then simply removing the caps 10 min before the training, would have resulted in incorrect concentrations. Measurements of the 2-propanone concentrations were made using a Bruël & Kjaer gas analyser, sampling continuously.

Modifications to the procedure, following the European Audit Project, allowed a 5% tolerance in the reference concentrations, and specified measurement of the unknown 2-propanone concentrations immediately before assessment by the panel, rather than several minutes before.

Selection and Training. Added to the capital cost of the equipment was the expense of paying the panel, trainer and travel costs.

In the panel selection, 50 people were presented with 12 concentrations of 2-propanone. Candidates were told the decipol values of four of the concentrations and had to estimate the values of the other eight. The 17 people who gave the best estimates were selected to be trained as panel members.

At the end of the training, it was possible to see how accurate the panel members had become in assessing the decipol ratings of 2-propanone samples. Speaking to panel members revealed that, as the only difference between these samples was their concentration, they learnt to use mainly intensity rather than acceptability to make their assessments, despite being instructed to use acceptability. When the panel was presented with samples other than 2-propanone, either in the decipolmeters or outside the laboratory, the assessments needed to be made considering acceptability, not intensity, and the ratings became much more spread. This is due to the natural variation in sensitivity and preference between panel members.

The votes might also depend on personal preference towards a particular substance, or on how pleasant the 2-propanone was perceived to be. Panel members who found the 2-propanone pleasant (and therefore more acceptable) might give a higher decipol rating for other substances. This is supported by feedback from the UK panels.

The ratings for samples of substances other than 2-propanone had to be reasonably consistent (within a specified standard deviation of the mean). Even if this was achieved, however, there was no certainty that the consistency would apply in a real office environment. Neither could validity be established without direct comparison with ratings given by a large panel of untrained assessors.

Using a reference gas other than 2-propanone could improve this. By analysing samples of real building air, it may be possible to develop a reference gas that more closely represents the air that the panel have to assess during the building tests. This reference gas could be produced at a number of concentrations, to give known and unknown decipol values for panel training.

The procedure has no way of dealing with personal or cultural differences, so comparing results from a different panel of people, or results from different countries is impossible. To provide quality assurance, every panel could have one or more samples in common that were not 2-propanone (for example, each panel might assess a square of the same carpet, or vinyl flooring).

Time Schedule for Field Work. Scheduling the training and testing into one day was very difficult. The panel met in the morning at BRE, and were calibrated and tested with the 2-propanone samples and other samples. They were then transported to the buildings being audited, to make the decipol assessments. With the training, travelling and building audit, the panel were required for up to 11 h on each test day, and the experimenters for longer.

Questionnaires were given out to the building occupants in the areas where measurements were being taken, and in other parts of the building. The procedure suggested that questionnaires and sensory measurements should be completed in 2 h, from lunchtime onwards. This meant that the response rate for the questionnaires was lower than it would have been, because many people were at lunch. For the panel's sensory measurements, the timetable meant that decipol ratings for rooms and corridors were often influenced by food smells.

In subsequent field work carried out by BRE, the sensory panel started assessments earlier, in order to finish before lunch. The questionnaires were handed out at the start of the day, and collected early in the afternoon.

Access to Fresh Air. One of the most difficult parts of the organisation for the sensory panel was finding access to fresh air between ratings. Many large office buildings are mechanically ventilated or air-conditioned, and in nearly all of these buildings, the windows are sealed. So there was often no access to outside air, other than at the main entrances to the building, or on the roof. This meant that the panel walked through the building to get to the measurement locations; even if they were to breathe through their mouths, they would still be adapting to the building air. Having a fresh air point extremely close to the measurement locations would affect the ventilation measurements, and would therefore not be sensible.

The reason for fresh air between ratings is to 'clear' the nose before the next rating. However, within the UK, large office buildings are rarely built in open country – most are in the middle of towns or cities, or next to major roads. The buildings in areas where the outside air is more polluted are more likely to be mechanically ventilated. So in the naturally ventilated buildings where there is easy access to outside air, the outside air is fairly fresh, but in the mechanically ventilated buildings, where there is little or no access to outside air, the outside air may not be very fresh, and is therefore of questionable benefit to the panel.

The Findings of the European Audit Project

One of the benefits originally claimed for the decipol was that high decipols would account for sick building syndrome (SBS), so reducing decipol levels would solve the problem of SBS. Hence, one of the most important objectives of the project was to investigate whether a perceived air quality rating by an independent panel could be used to predict occupant comfort and health, or occupants' opinions of air quality, odour and stuffiness. If it could, then perhaps the sensory panel could be used in some situations instead of the traditional occupant questionnaires or air quality measurements. Another important objective was to compare the panel's perceived air quality votes with the ventilation rates for the audited buildings.

Analysis of the European Audit Project data showed no statistically significant correlations between the sensory panel's decipol ratings and any of the questionnaire results (symptoms or ratings of the indoor air quality). An example is given in figure 1 ($r = 0.032$, $r^2 = 0.001$, $p = 0.812$). These findings indicate that the decipol cannot be used in place of the questionnaire. One reason for this lack of correlation is that the sensory panel made an immediate assessment of the air quality in each location, whereas the occupants were, to some extent, adapted to their office environment, and made a long-term assessment.

Also, recent laboratory tests [17] show that the decipol votes given by sensory panels to samples of fixed pollutant concentration depend on the temperature and humidity of the air. Hence, corrections would need to be made for these parameters if the pollution content of different indoor environments were to be compared. If the temperature and humidity effects vary significantly among pollutant types, then applying the corrections would become very complex and require a great deal of data (in addition to the corrections necessary for pollutant type without regard to temperature and humidity [7]).

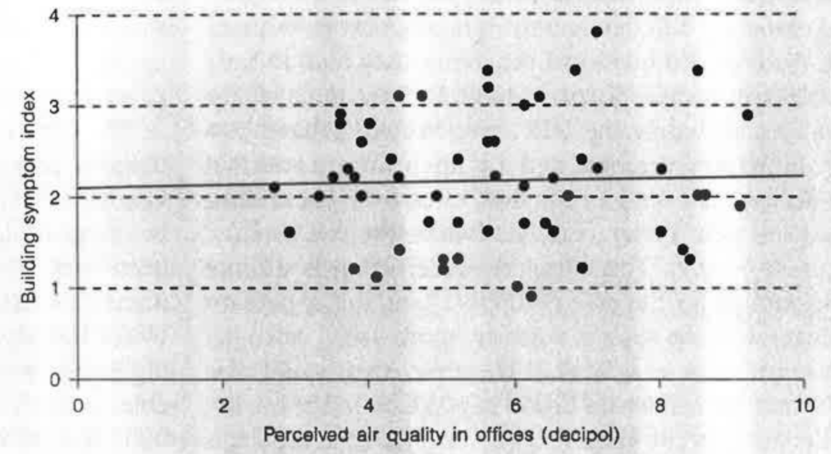

Fig. 1. Health of occupants compared to perceived air quality.

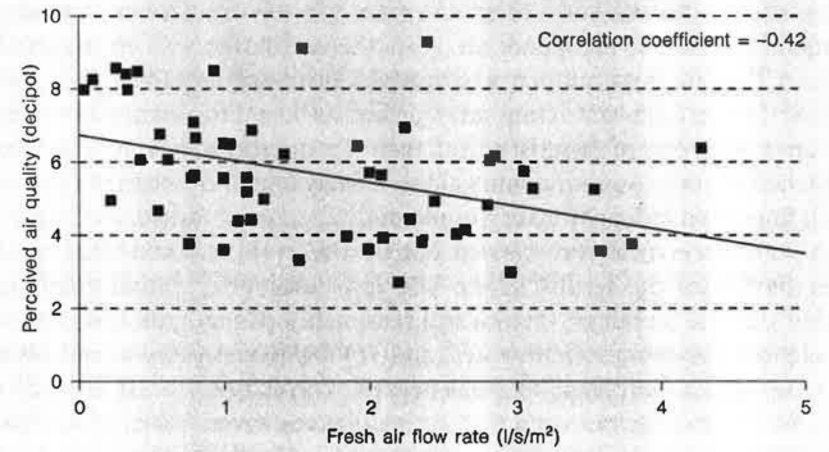

Fig. 2. Perceived air quality versus fresh air flow rate.

Comparing decipol votes to physical measurements produced few significant correlations. There was no correlation between total volatile organic compounds (TVOC) concentrations and decipol votes, and no correlation between decipol votes and particulate measurements. A statistically significant correlation was found between decipol votes and carbon dioxide levels, but with a very low correlation coefficient.

The decipol votes can also be compared to the ventilation rates. Of particular interest was the comparison between decipol votes and outdoor air flow rate in offices. In this case, when some outliers are excluded, there is a relationship ($p < 0.01$), between the decipol votes and the outdoor air flow rate. Figure 2 shows the figure used in the international report [10]. In that report, a regression line is added, and the report concludes 'that buildings with high ventilation rates had better perceived air quality than other buildings'.

This would appear to support the theory that the decipol can be used to predict required ventilation rates. However, what is not made clear by the report is the low correlation coefficient for this relationship ($r = -0.42$, $r^2 = 0.18$), which means that 82% of the variance in decipol values is not explained by the ventilation rate. This is not a high enough correlation coefficient for the regression line to be used as a predictive tool; it would need to be much higher (for example, $r = 0.9$). In figure 2, the 95% confidence limits on the regression line are approximately

± 1 litre·s^{-1}·m^{-2} (equivalent to ± 10 litres·s^{-1}·person^{-1} with an occupant density of 10 m^{2}·person^{-1}).

Among the different countries taking part in this project, the type and quality of the rooms they used to train the sensory panels varied widely. At least three of the countries, including the UK, were known to have purpose-built training rooms, and it is interesting to note that the decipol and outdoor air flow rates from these three countries were better correlated than the 'all-country' results (r = –0.7). This correlation coefficient is still not good enough for use as a predictive tool, but it perhaps indicates that the decipol votes are more useful when the ideal procedure is followed. However, this would also show that the results are highly dependent on the quality of the training procedure, and the practical problems associated with this are considerable.

It also needs to be made clear that a relationship between decipol votes and ventilation rates is of little value unless the decipol votes themselves are a proxy for occupant response to the indoor air. Also, the ventilation rates in the buildings audited averaged 25 litres·sec^{-1}·person^{-1}; if this high ventilation rate was not sufficient to prevent a high level of dissatisfaction, then it is questionable whether addressing air quality alone is likely to make much impact on indoor climate complaints.

In subsequent fieldwork carried out by BRE [18], a fuller picture of the results in the UK has developed. Within the UK buildings, there was a reasonably strong correlation between decipol votes and TVOC levels. There was also a significant but weak negative correlation between BSI and decipol votes (indicating that the worse the perceived air quality, the healthier the occupants were). This is not evidence for a causal relationship, but an indication of the type of results the method produces.

What Can Decipols Be Used for?

Decipol votes do not provide any basis at all for predicting the health and comfort of the occupants of office buildings. Decipols are not, on current evidence, the best method currently available, but in fact predict no better than chance. The most likely explanation for this is that the occupants have adapted to odours but, over time, are increasingly affected by irritants. The panel gives an immediate impression of the air quality and is therefore more influenced by odour and less by sensory irritation.

Parine [19] also points out that people's judgement of annoyance depends on what they are used to. This is well-established with noise, and Parine argues that the same applies to air quality. There is no absolute level at which air quality is acceptable – the threshold of acceptability will move depending on the current conditions (sensory adaptation) and past conditions (expectations, cognitive adaptation). Using visitors to assess air quality therefore ignores the expectations of occupants, and the long-term adaptation to their environmental conditions.

The different time course of response to odours and irritants presents a problem because, it can be argued, ventilation rates are already set to satisfy 'visitors' to a building, using results obtained in the 1930s [20]. We need to be wary of the argument that, to use decipols is merely a continuation of what has been done in the past. Unfortunately, we are not now in a position to monitor indoor air quality in the 1930s. Otherwise, we might be able to test the hypothesis that the main pollutants in buildings then (other than tobacco smoke) were people and were odorants rather than irritants. Hence working from the immediate impression of visitors would provide comfort for occupants with a good margin of error represented by the capacity to adapt.

In modern buildings, more of the indoor pollution is likely to come from building materials and the ratio of irritants to odorants may well be higher; hence the reactions of adapted occupants should be measured, rather than the immediate impressions of a visiting panel. What worked in the past may simply be inappropriate in modern buildings; one thing that is clear is that, with or without decipols, the issue of pollutants from building materials, from the materials and equipment in offices, and from ventilation systems, cannot be ignored.

It remains to be seen whether efforts to improve the decipol approach will be successful in creating a technique that can reliably represent the reactions of the occupants of buildings. In the meantime, there are two applications of the decipol which remain viable.

First, sensory panels may be used to predict how visitors would react when first arriving in a building. This has not been explicitly demonstrated but it would follow from the nature of the method. This is a more limited application but could be of value for buildings where first impressions matter (for example when creating a good impression with clients). This function could alternatively be performed by the usual staff of the building making an evaluation on arriving in the building.

Second, the sensory evaluation procedure has some potential for use in laboratory-based testing. One use of the sensory panel is the testing of different materials, to prevent the installation of highly odorous materials in offices. It is preferable to furnish a building with low-odour materials in the first place, than to have to increase ventilation rates later on. This application would depend to some extent on improving our knowledge of how different types of odour interact. Materials would also need to be checked to make sure that concentrating on odours did not result in higher emissions of irritants.

Conclusions

There are theoretical and methodological failings in the derivation of the olf and decipol that have not been resolved.

There are also practical and economic problems with carrying out the sensory panel procedure, particularly in the field work.

Decipol votes are not correlated with occupant health or comfort, or to any useful extent with physical measurements.

The decipol should not be used as an alternative to questionnaires to represent occupant health, comfort or opinions, nor should it be used as a tool for assessing acceptability of ventilation rates, or predicting required ventilation rates.

Pollution from sources other than people and tobacco smoke does need to be considered in selecting materials and in setting ventilation rates.

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