

MEASURING ODOR QUALITY OF BUILDING MATERIALS IN AN ODOR SPACE

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Abstract

We can discriminate a huge number of odors. Still, the perceptual mechanisms responsible for perceived odor quality is not well understood. The research goal was to define an odor reference space that may represent indoor air quality. Two observers scaled the perceived similarity of discernable emissions of all possible pairs of 30 building materials. Combined cluster and component analyses were used for identifying 12 potential odor references enabling a preliminary definition of the odor space. This odor space was partially validated and improved by individual differences scaling (INDSCAL) of seven observers' similarity matrices of odor qualities including 27 of the 30 building materials. Grounded in 13 odor references, a three-dimensional measurement space is provided for odor quality of building materials emissions and potentially also for the indoor air quality of non-industrial buildings.

Odor is a homogeneous perception and “the characteristic of an odor” is its *odor quality*. We lack words for describing adequately the numerous odor qualities we may perceive. Instead, the most efficient way may be to measure similarities among odors represented by pairs of odorous substances or emissions from materials. This approach would not superimpose a verbal descriptor system on the organization of odors in the odor space. The hedonic factor is known to be important in discrimination or classification of odor qualities. It may however be responsible for the large interindividual differences typically found in odor-quality experiments. Clustering and multidimensional theories and corresponding methods have been popular in determining the odor space (e.g., Wright & Michels, 1964; Woskow, 1968; Berglund et al., 1973; Gregson & Mitchell, 1974; Moskowitz & Gerbers, 1977; Davis, 1979; Lawless, 1989; Stevens & Connell, 1996). Multidimensional scaling of perceived similarities, among larger sets of odors, provides an ideal method to generate a *nonverbal representation* of odor quality.

The present experimental research focuses on finding and defining a *perceptual space of odor qualities* applicable to natural building materials emissions. In the future, such an odor space may be used for predicting and building indoor air quality in rooms.

The Experiment

Observers

Two or seven healthy women, 21 to 35 years old, took part in the experiments. None had allergy/asthma or chronic disease, sensory deficits or temporary illnesses. None used tobacco. Observers received monetary compensation for their participation.

Design and Odor Stimuli

Berglund et al. (1973) found large interindividual differences in similarity and pleasantness scales for liquid dilutions of 21 odorous chemical compounds matched in odor intensity. Because of natural lifetime experiences, interindividual differences are expected to be lower for odorous emissions from building materials than for single chemical compounds. The 27 (or 30) carefully selected odorous materials were (M = months; y = years used): Paint on gypsum board (2M); Filter (13M); Carpet (>20y); Sealant b (9M); Parquet floor a; Wooden floor (2M); Felt carpet (aged>25y); Pine wood plank; Chipboard; Carpet (2M); Insulation material; Ceiling (9M); Plaster; Sealant a (9M); Oil applied on wood; Filter (18M); Filter; Parquet floor b; Gypsum (2M); PVC (2M); Varnish on wood; Linoleum (9M); Carpet a (9M); Polyolefin; Glue on pine wood; Oak fillet; and Linoleum. Three additional materials were also included for two observers: Fillet (floor/wall), Newspaper, and Carpet b (9M). All materials were wrapped in aluminum foil and stored at constant room temperature and humidity.

The experiment was conducted in the air-conditioned clean-air laboratory at the Gösta Ekman Laboratory building. The indoor air of the laboratory is kept at constant temperature and humidity. During the experiment, the clean-air laboratory also served as storage room for the aluminum-foil wrapped building materials. The experimenter presented building materials at the nose of the blindfolded, seated observer (TEMPUR Sleep Mask). Between sniffs, the experimenter unwrapped and rewrapped the stimulus in aluminum foil. Each observer took part 3 hours daily, pauses included, and the whole experiment lasted 5 days. An observer thus completed the experiment in ca. 15 hours.

The Scaling of Similarity of Emissions from Building Materials

All possible pairs of the 27 (or 30) different stimulus materials were presented and scaled with regard to *similarity* on a scale from 0 to 100%, where 0 % represented no similarity at all and 100% complete similarity. The observers were specially instructed to focus on the similarity in *odor quality* and were asked to try to disregard potential differences in odor intensity. In a pilot experiment, observers found it difficult to remember the odor quality of the first material in a pair, long enough for comparing it with the odor quality of the second material. In order to avoid this short-term memory problem, a special irregular presentation order was constructed.

Table 1. First selection of a set of potential odor-quality references for an odor space.

12 Building Materials References	New Ref No	Observer 1 h ² (10 comp)	Observer 2 h ² (9 comp)	Observer 1 (5 clusters)	Observer 2 (4 clusters)
02. Paint on gypsum	09	.90 (4, 9)	.77 (4)	C2	C3
08. Wooden floor 2M	02	.86 (3, 1, 10)	.89 (8)	C5	C3
10. Pine wood	-	.92 (1, 5)	.84 (1)	C1	C2
11. Chipboard	08	.86 (1, 4)	.89 (1)	C1	C2
17. Sealant 9M a	10	.79 (2)	.86 (9)	C5	C4
18. Oil applied wood	07	.80 (5)	.87 (1)	C5	C2
19. Filter 18M	05	.84 (2)	.88 (3, 5, 6)	C3	C4
20. Filter	12	.78 (4)	.78 (6, 1)	C4	C1
23. PVC 2M	13	.80 (6, 3, 5)	.81 (3)	C4	C1
25. Linoleum 9M	06	.91 (7)	.79 (1, 2)	C3	C4
28. Glue on wood	04	.79 (1)	.88 (7, 5, 6)	C5	C4
30. Linoleum 10y	-	.78 (2)	.83 (2, 1)	C3	C4

From a full matrix of stimulus materials, rows were randomly selected out of the 27 (or 30) possible rows until no row was left to select. To save experimental time, pairs in the main diagonal were excluded, leaving 26 (or 29) pairs to be judged in each row. For every pair, the observer was allowed to smell repeatedly until they felt confident to report a similarity value. A 15-min pause was interspersed between each set of 26 (or 29) pairs in a row. The observer spent these pauses in a specially ventilated clean-air “waiting” room of the laboratory. In total, 702 (or 870) similarity values were collected from each of 7 observers. Thus, asymmetric matrices of similarity were analyzed.

Results

Principal Components Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were applied to the similarity matrices of two observers and a candidate set of reference odor qualities was discerned. As a semi-cross validation, similarity matrices of seven observers were then mapped by Individual Differences Scaling (INDSCAL), Carroll and Chang (1970). The software used was from the SPSS 13.0 program package (Norusis, 2005).

Selection of Potential Reference Odor Qualities for Defining an Odor Space (HCA & PCA)

The similarity scale of 0-100% was transformed to a 0-1 scale, and unity was entered into the main diagonal. HCA was applied to the similarity matrices (30 x 30) of two observers. In order to obtain *metric distance* in Euclidean space for the scale indicating when the clusters combine, the furthest away (or maximum) method was used (Baird & Noma, 1978, p. 225). Five or four distinct odor-quality clusters of the building materials were obtained for Observer 1 (O1) and Observer 2 (O2), respectively; the order of the clusters ranked differently, Table 1.

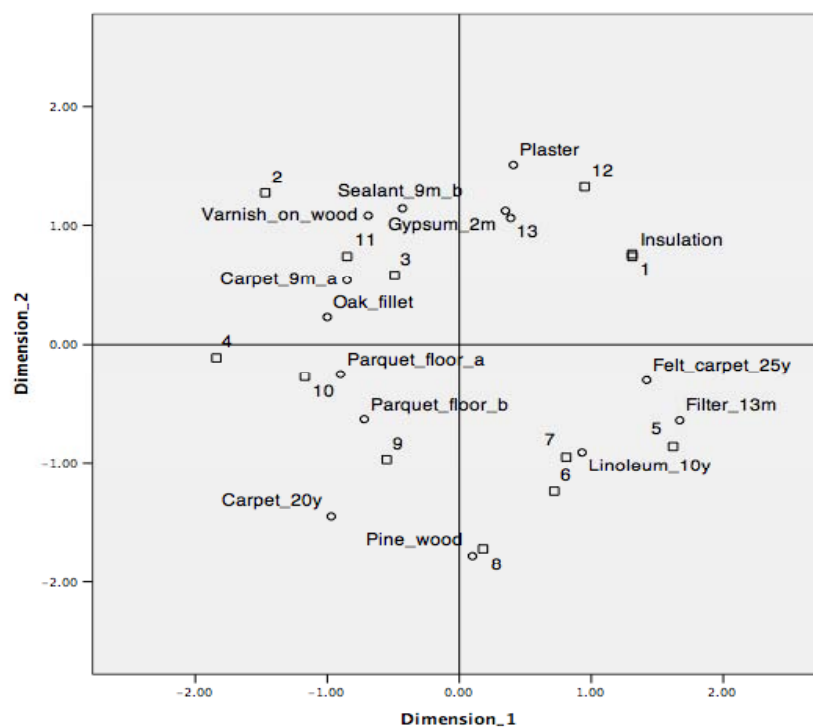


Figure 1. Dimension 2 vs. Dimension 1 of the three-dimensional INDSCAL solution based on dissimilarities of odor qualities of 27 building materials (27 x 27 asymmetric matrices of 7 observers; Euclidean model; Stress = 0.46; RSQ (squared correlation) = 0.19).

Number of PCA-extracted components was according to eigenvalues > 1 : they were 10, 9, and 8 components for O1, O2, and the group of the two, respectively. Total variance explained was in mentioned order: 81, 79 and 67%. For the 30 materials, the communalities (h^2) were higher for O1 (0.63–0.92) and O2 (0.62–0.90) than for the two together (0.51–0.85). This indicates disagreement *or true* interindividual differences in perceived odor quality. The concordance was low ($r=0.12$, $n=870$) between the two observers' asymmetric *similarity matrices*. Still, the building materials with the *highest communalities* in the two individual PCA solutions provide a very good representation of a common odor space. Table 1 presents the set of 12 candidate building-material references based on highest communalities (h^2) and the individual distinct clusters (C1-C5) produced by the two observers' HCA.

A Three-Dimensional Odor Space based on Multidimensional Scaling (INDSCAL)

The seven observers' similarity scales (0-100%) were transformed to dissimilarity scales (1-0). The individual differences (weighted) Euclidean model (INDSCAL) was applied to the individual asymmetric dissimilarity matrices of the 7 observers (27 x 27; due to redundancy, 3 building materials out of 30 were excluded). The stress value for the two weighted solutions for the group of 7 participants improved from 0.50 (for 2 dimensions) to 0.46 (for 3 dimensions). Figure 1 and 2 present the 3-dimensional INDSCAL solution for the 7 observers' dissimilarity matrices. Dimension 2 and Dimension 3 are plotted against Dimension 1 in Figure 1 and 2, respectively. The two figures show a good spread of the odor qualities created by the 27 building material emissions. See second column of Table 2 for the building materials labelled with numbers 1 to 13 in Figures 1 and 2.

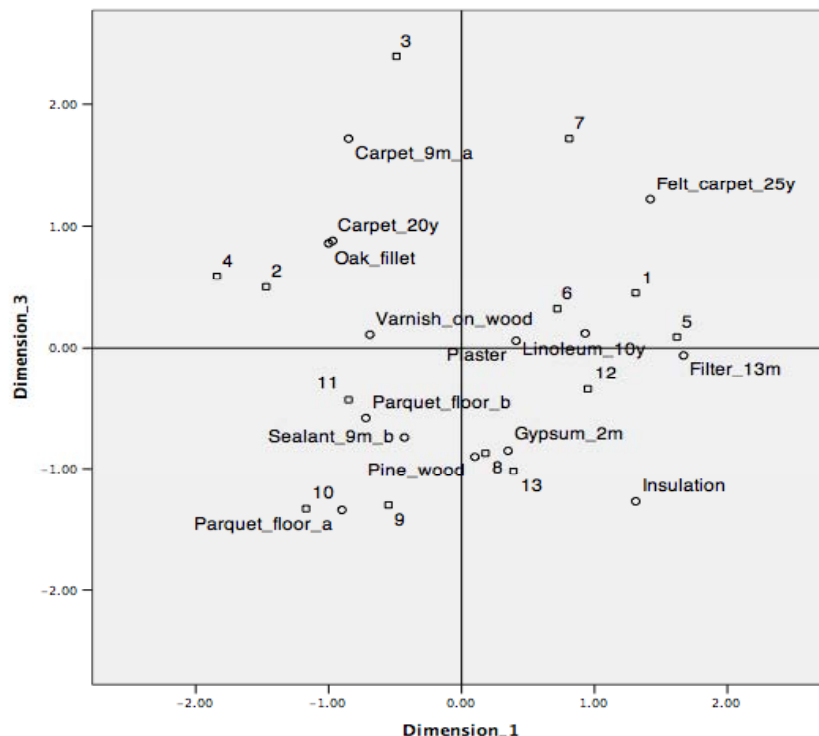


Figure 2. Dimension 3 vs. Dimension 1 of the three-dimensional INDSCAL solution based on dissimilarities of odor qualities of 27 building materials (27 x 27 asymmetric matrices of seven observers; Euclidean model; Stress = 0.46; RSQ (squared correlation) = 0.19).

Selection of Potential Reference Odor Qualities for Defining an Odor Space (INDSCAL)

In the 3-dimensional INDSCAL solution, 10 of 12 candidate reference odors were well placed and spread in a representative way in the odor space. Table 1 lists these 10 references by new numbers (2nd column), which are also shown with labels in Figures 1 and 2. The results obtained from the 7 observers by INDSCAL thus cross-validate the candidate reference odor qualities obtained from the two participants with another technique (HCA and PCA). The new numbering of the reference odor qualities was adopted from the results presented in Table 2, based on the data from 7 observers.

Table 2 summarizes the position of the odor qualities of the 27 building materials in the 3-dimensional INDSCAL solution; the odor qualities are sorted into octants (1-8). An octant is one of the eight divisions of a Euclidean 3-dimensional coordinate system (cf. 2-D quadrant and 1-D ray). Each of the 3 dimensions of an imagined “cube” has positive (+) and/or negative (-) signs in each octant and the eight octants are organized in two layers (see Table 2), starting from the upper, right, front corner with positive coordinate values in the three dimensions (+++), named Octant 1. The Octants 1-4 are situated in the upper layer of the cube and Octant 5-8 in the lower layer. Thus, Octant 1 is above Octant 8, Octant 2 above Octant 7, Octant 3 above Octant 6 and Octant 4 above Octant 5.

Based on the 3-dimensional INDSCAL, Table 2 presents also our new set of 13 reference odor qualities of building materials (middle column). These consist of the earlier 10 candidate references (Table 1, 2nd column) and three new references (1–Ceiling 9M; 3–Carpet 2M; 11–Polyolefin). The latter, new ones helped to cover better the space within Octant 1, 2 and 7. Two of the earlier candidate references were moved out because they were too close to other reference odor qualities in Octant 4 and 5 (cf. Table 1 and 2).

Table 2. The odor quality of building materials classified in a 3D-measurement space (octants), defined by 13 reference odor qualities.

Octant of 3D INDSCAL	Reference Qdour Quality	Odour Quality of Other Materials
1 +++	1. Ceiling_9M	Plaster
2 -++	2. Wooden_floor_2M 3. Carpet_2M	Carpet_9M_a Oak-fillet Varnish_on_wood
3 --+	4. Glue_on_wood	Carpet_20y
4++	5. Filter_18M 6. Linoleum_9M 7. Oil_applied_wood	Felt_carpet_25y Linoleum_10y
5+-	8. Chipboard	Filter_13M Pine_wood
6---	9. Paint_on_gypsum 10. Sealant_9M_a	Parquet_floor_a Parquet_floor_b
7-+-	11. Polyolefin	Sealant_9M_b
8++-	12. Filter 13. PVC_2M	Gypsum_2M Insulation

Footnote. Octants 1 to 8 are defined by position of signs, e.g., -+- refer to D1, D2, & D3 that have negative, positive & negative signs (= Octant 7).

Conclusions

At this stage of the research we draw the following conclusions:

1. The coordinate values of 13 reference odor qualities constitute our new measurement system (3-D system presented in Figures 1 and 2) of odor quality (a) of building materials and potentially also (b) of indoor air quality of non-industrial buildings.
2. The octants constitute a classification system, which may serve in practice, particularly in applications where residents have reported symptoms associated with the sick building syndrome or chemical sensitivity (Berglund & Zheng, 2002).
3. An odor space grounded in the emissions from representative reference materials can be used for designing and calibrating chemical instruments such as the electronic nose. The identification and measurement of the numerous odor qualities that may be perceived would require painstaking research far beyond our current odor perception.

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