Building Science Group
Prof. Dipl.-Ing. Andreas Wagner
Englerstraße 7, Geb. 20.40
76131 Karlsruhe

Tel.: +49 721 608 - 2178
Fax: +49 721 608 - 6092
www.fbta.uni-karlsruhe.de

Occupant satisfaction as an indicator for the socio-cultural dimension of sustainable office buildings

Project Leader: Prof. Andreas Wagner

Main Investigator: Karin Schakib-Ekbatan (B.A.)

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1 Project objectives

Offices represent an important work environment and are a worthwhile challenge in the context of designing sustainable buildings with low energy consumption, high comfort and appropriate functionality for the employees. Certification systems and labels are supporting instruments for current technical and socio-political discussions and for the practical application of political objectives and concepts in the real estate market (Kaufmann-Hayoz et al. 2001). The predicted socio-cultural quality (thermal, visual and aural comfort, air quality and others) as part of the German `Sustainable Building´ Quality Label for office and administrative buildings (Federal Ministry of Transport, Building and Urban Development) is based on standards, documents and inspection.

Against this background the main objective of the project `Occupant satisfaction as an indicator for the socio-cultural dimension of sustainable office buildings´ was the development of a time- and cost-effective as well as praxis-oriented instrument for the evaluation of building performance from the occupants' day-to-day experiences with comfort at the workplace. The comfort parameters are obtained from standardised surveys. The occupants' votes should be processed on different information levels:

(a) A combined overall building index allows the ranking of single buildings in comparison to a building stock on an aggregated level.

(b) Beyond this index differentiated information on the perceived comfort is extracted for a comprehensive building assessment. By examining single comfort parameters information about strengths and weaknesses of a building from the occupants' perspective can be obtained. The outcome supports monitoring procedures, provides guidance for improvement and contributes to evaluate interventions.

A further aim was the development of an easy to handle instrument for assessing building performance by paper-pencil as well as PC-based surveys. A report sheet based on automated routines for analyses should graphically represent the results of the survey. Hence, the assessment of a great amount of buildings would be possible in a short time.

2 Methods and results

2.1 Statistical analyses to develop an overall building index

An index aims to summarize a variety of variables in a manageable and easily communicable way. With respect to the occupants' satisfaction summarizing questions *(`Overall, how satisfied are you with …?´*) represent the relevant indicators for the overall index: thermal, visual and aural comfort, furniture, spatial conditions (e.g. office type) and the overall functionality of the building. The question at hand is which statistical procedures should be applied to build the index. With regard to a manageable and easily communicable index a score based on mean values according to the five-point scale in the questionnaire (-2 = `*very dissatisfied´* to 2 = `*very satisfied´*) would be a smart solution.

The database in Germany for building performance from the occupants' perspective is still small. Since 2004 surveys are conducted by the Building Science Group of the Karlsruhe Institute of Technology (KIT), initially in energy efficient buildings in the research program `EnOB: Research for energy-optimised construction´ (www.enob.info). In order to enlarge the database of the Building Science Group and to extend the scope of the considered buildings more older and retrofitted buildings were assessed within this project since 2008. As an additional resource, a part of the large database of the Center for the Built Environment (CBE, University of California, Berkeley; www.cbe.berkeley.edu)[1] was analysed to test statistical methods for developing an index. The questionnaire applied in the German field studies by the Building Science Group is based on the surveys done at the CBE, therefore the data acquistion is comparable. Two exploratory methods for representing multivariate datasets were chosen to prove if there is statistical evidence for an overall building index. The aim was to prove if large sets of variables could be reduced to few dimensions by aggregating individual-level data to construct measures for units at a higher level. Analyses of the CBE-database showed evidence for an overall building index. For lack of space in this short report we only refer to the results of the analyses with the German database. For more information see the final German project report.

2.1.1 Multiple correspondance analyses

Correspondence Analysis is a method of factoring multiple categorical variables and displaying them in a property space which provides a global view of the data useful for interpretation (Benzécri, 1992; Cibois, 2007; Greenacre, 1993). Variables can be considered simultaneously. The primary goal is a graphical display of contingency tables, i.e. rows and columns. The association of the variables is visualized on a bi-plot in two or more dimensions. Eigenvalues reflect the relative importance of the dimensions. The first dimension always explains the highest inertia (variance) and has the largest eigenvalue, the next the second-highest, and so on. Points (variables) are plotted along the computed factor axes, i.e. dimensions (Figure 1). The map can help detecting structural relationships among the variable categories. In contrast to the Chi-square test which shows if there is a relationship, the correspondence analysis shows the character of the relationship between variables. Very similar objects would be grouped close together, strongly differing objects would be very far from each other along an axis. Plausibility for aggregating indicators to an overall building index (Reed, 2002) would be given if the first dimension showed the ordinality of the outcome for the comfort questions in terms of a scale for satisfaction at the workplace. Analyses were carried out with the French software Trideux (http://pagesperso-orange.fr/cibois/Trideux.html).

Building sample

Analyses were carried out with a part of the german database (23 buildings, N = 1,329). Surveys from field studies during winter months 2006 to 2009 were included. The sample represented the best datapool based on comparable questionnaires. 69 variables were included in the analyses.

[1] We would like to thank the following persons at the CBE for their constructive support and for fruitful discussions: Prof. Ed Arens (Director), Prof. Gail Braiger (Associate Director) and especially John Goins (Research Specialist).

Results

Figure 1 shows the dispersion of the data profiles, representing the correlation of the single comfort parameters. Along the X-axis the ordinal scale for comfort at the workplace in the first dimension is identifiable.

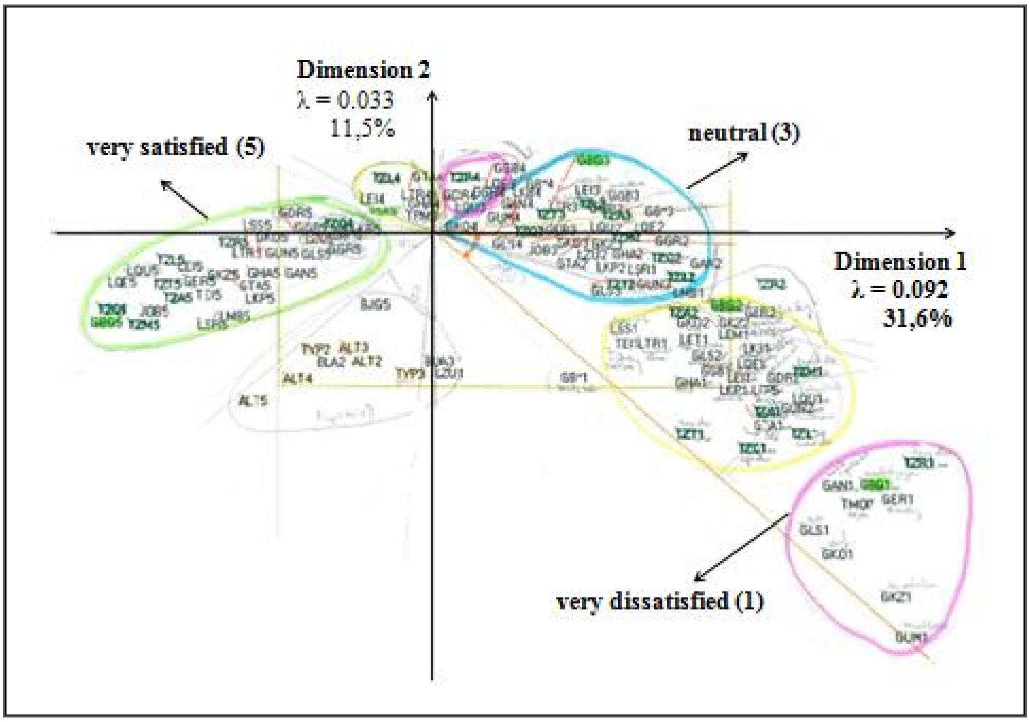

Figure 1 Output for the Correspondence Analysis with Trideux after interpreting and marking of relevant outcomes. Eigenvalue λ > 0,1 = strong correlation between variables, λ 0,01 bis 0,1 = standard, λ < 0,01 = weak correlation, could be at random, (Cibois, 2007). Sample: 22 buildings, number of participants in the survey = 1,329. 69 variables were chosen concerning satisfaction with comfort parameters at the workplace, including `*Overall…*´-questions.

The grouping follows the ordinal scale from 5 (`*very satisfied*´) over 3 (`*neutral*´) to 1 (`*very dissatisfied*´)[2]. The value for the first dimension (λ = 0.092) with 31,6% shows the strongest contribution for the explained variation and can be interpreted as a dimension for satisfaction. The value for the second dimension (Y-axis) is too low to be of relevance (λ = 0.033; 11,5%). With respect to the great number of variables in the analyses the value for the first dimension is notably high. Finally the result reveals that the precondition for aggregating the comfort indicators to an index is given.

The Figure shows a parable: The `horseshoe´- or `Guttman´-effect in the graph is typical for the representation of ordinal characteristics in the data revealing non-linear dependencies between the axes (v. Rijckevorsel, 1986).

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[2] The codes -2, -1, 0, 1, 2 had to be recoded for the mathematical operations.

2.1.2 Principal Component Analysis

PCA is mostly used as an instrument in exploratory data analyses and for creating predictive models. PCA is the simplest of the true eigenvalue-based multivariate analyses. Its operation can be thought of as revealing the internal structure of the data in a way which best explains the variance in the data. Once again, as with the correspondence analysis, the aim is to reduce a set of variables to a set of underlying superordinate dimensions.
The basic idea of optimal scaling is to transform the observed variables (categories) in terms of quantifications for further computations. Ordinal values from the Likert-scale (*`very dissatisfied´* = 1 to *`very satisfied´* = 5) are transformed into metric values which can be used for further computations. PCA involves the calculation of the eigenvalue decomposition of a data covariance matrix. Results are usually discussed in terms of component scores and loadings.

The aim of the analyses was to test if the questions regarding comfort aspects like temperature etc. *(`Overall, how satisfied are you with …?´*) would be represented by one dimension and if they could be considered as a scale to describe satisfaction with comfort at the workplace. Analyses were carried out by applying PASW Statistics (Predictive Analytics Software, formerly SPSS).

Building sample

Data from surveys conducted in 14 buildings (n = 867) during winter months in 2008 and 2009 with identical questionnaires were included.

Results

The analyses revealed that all variables load well on the first dimension (eigenvalue 3,316), and can be considered as a scale for general satisfaction with the workplace. High scores mean a high level of satisfaction: people who are satisfied with one comfort parameter are also satisfied with the others. Dimension 2 has no importance (eigenvalue 0,949), because dimensions with eigenvalues smaller 1 have less weight than the original single variables themselves. Nevertheless dimension 2 is quite interesting, because it shows both positive and negative scores and seems to represent a kind of polarisation by means of indoor climate conditions versus spatial conditions, furniture/layout and acoustics. Possibly further analyses by means of building characteristics may reveal an explanation for this finding.

Additionally, it was tested if differently computed `comfort´ scales including the six comfort parameters would correlate. Besides the new metric variable obtained with the object score for dimension 1 from the optimal scaling, a weighted `comfort´ scale was computed. This scale was based on multiple regression-analysis with the six comfort parameters (*`Overall…´* questions) as predicting variables and the question *`Overall, considering all aspects, how satisfied are you with your workplace conditions?´* as dependent variable. A third scale, (`comfort´ scale – summed-) was computed by simply summing the mean scores of the six comfort parameters. Table 1 shows a strong correlation for the `comfort´ scale based on simply summed mean scores with the other two differently computed `comfort´ scales (regression-analysis and optimal scaling). All three scores for the differently computed `comfort´ scale are highly correlated as well.

Table 1 Correlation Coefficients for different `Comfort´ Scales

		`Comfort´ Scale **-summed-**[1]	`Comfort´ Scale **-weighted-**[2]	`Comfort´ Scale **-object score for dimension 1-**[3]
`Comfort´ Scale **-summed-**[1]	*r*	1	**,965****	**,975****
	p		,000	,000
	N	867	867	867
Comfort´ Scale **-weighted-**[2]	*r*	**,965****	1	**,940****
	p	,000		,000
	N	867	867	867
`Comfort´ Scale **-object score for dimension 1-**[3]	*r*	**,975****	**,940****	1
	p	,000	,000	
	N	867	867	867

[1] = sum of simply added mean scores for satisfaction with single comfort parameters,
[2] = standardised prediction value from regression analysis,
[3] = standardised prediction value for dimension 1 from optimal scaling
r = correlation coefficient, *p* = value for probability of error (level of significance), *N* = number of participants in the survey.

The results for this sample reveal once again that a manageable index based on mean scores can be considered as acceptable.

2.1.3 Overall building index

Beyond occupants' ratings concerning their workplace the experiences of the occupants with the entire building is of importance when it is intended to give a comprehensive overview by means of an index. The modified latest questionnaire covers items which address this issue. Occupants rate a subset of items (e.g. maintenance, restrooms, conference rooms, zones for informal contacts, security) as well as a summarizing question (`*Overall, how satisfied are you with the building in general?´*, reliability for the 18 items Cronbach's $\alpha$ = .91). The mean score for the summarizing question `*Overall, how satisfied are you with the building in general?´* was added as a further indicator to the final building index. Data of our field studies revealed that occupants spent nearly 90% of their time in their office and only 10% in other areas of the building, thus the six comfort parameters for `workplace satisfaction´ build the main part of the `overall building index´.

The scale reliability (six indicators for satisfaction with workplace conditions and the added indicator for the overall satisfaction with the building) of this final index was tested, showing Cronbach's α = .82. Additionally, an explorative factor-analysis was carried out testing if the precondition for the Principal Component Analysis (PCA) with optimal scaling for the final `overall building index´ is given. The assumption in factor-analysis is that single indicators are highly correlated. A high value for the Kaiser-Meyer-Olkin-statistics (0,883) shows that homogeneity in the data is given.
The subsequent computations by PCA revealed a one-factor solution with high positive loadings for all seven indicators (> 0, 7) and an eigenvalue greater 1 (3,856; residual eigenvalues < 1). Figure 2 illustrates the facets of the final `overall building index´.

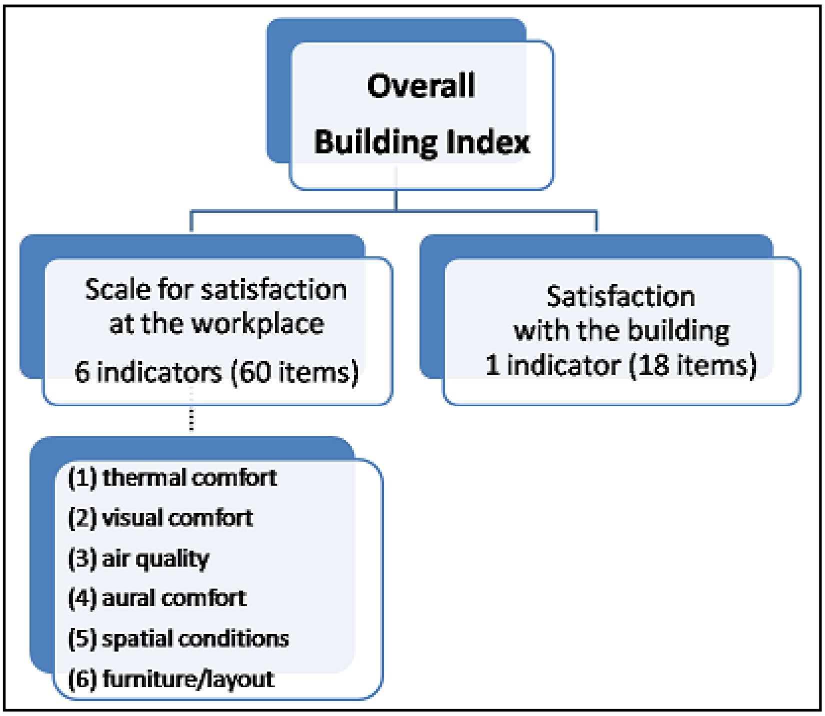

Figure 2 Final Overall Building Index

2.2 Development of an instrument for user surveys

An easy to handle as well as time and cost effective instrument was developed which provides a paper-pencil questionnaire as well as a PC- and web-based version for extensive assessments. Based on automated analysis routines a report sheet (Figure 3) shows the outcome of surveys:

- the overall building index,
- the mean scores for single comfort parameters,
- the distribution of frequencies for satisfaction given in three categories (*very dissatisfied/dissatisfied*, *neutral* and *satisfied/very satisfied*).

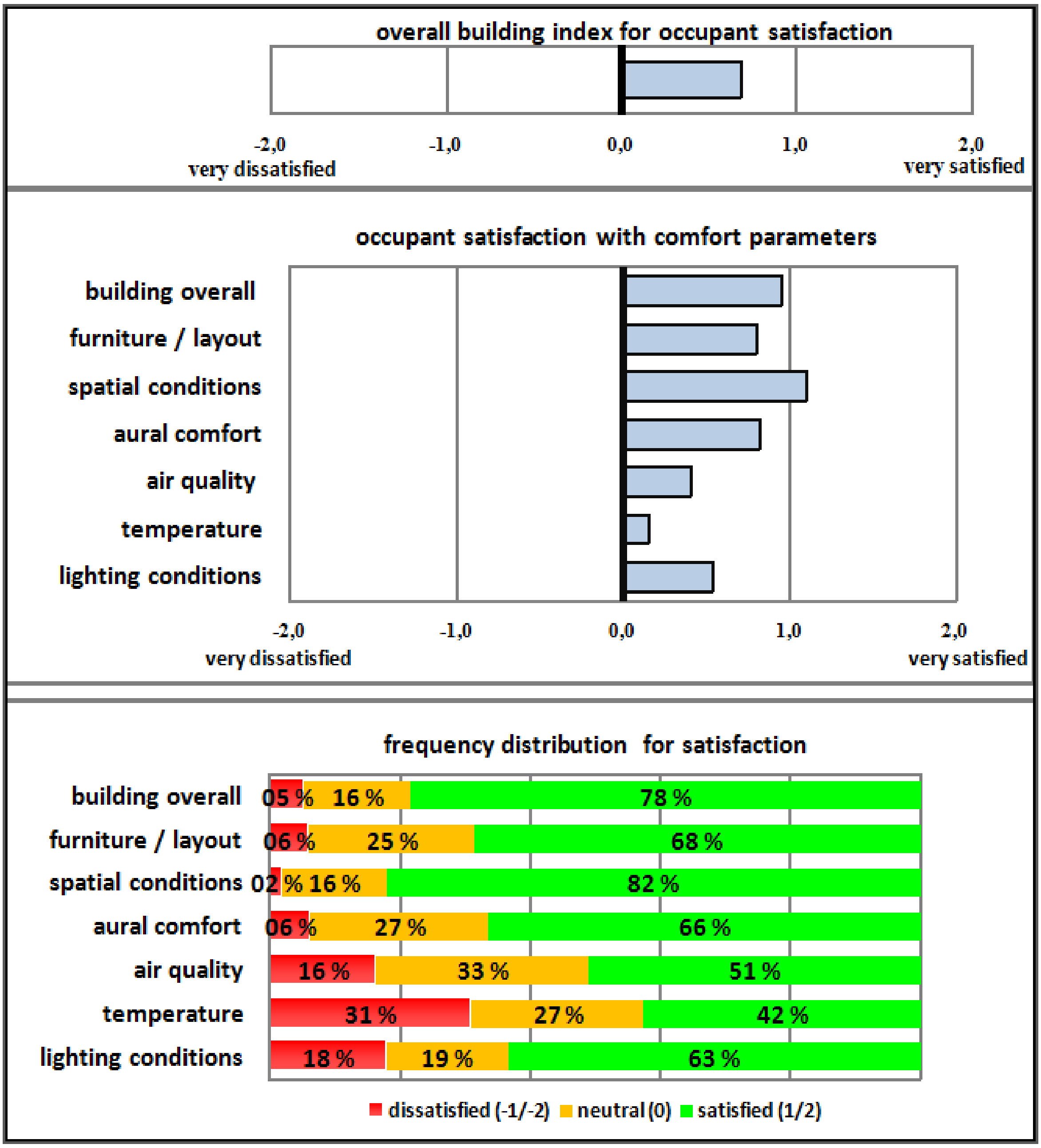

Figure 3 Exemplary report sheet

If an online-survey cannot be conducted in a building, the advantage of the instrument is that data entry can be done manually in an Excel table and that the data can be quickly imported in the report sheet as well. In an accompanying guide information for the implementation and evaluation of surveys is given.

3 Conclusion

The results revealed that by means of the applied statistical methods an overall building index based on mean values could be developed. A weighting of the comfort parameters was not necessary. The comparison of a weighted and a simple summed up score represented the included comfort parameters as a homogenous scale for satisfaction. Hence, for the first time a score for the building performance from occupants' perspective is available for the real estate market when it comes to evaluation of building stocks and to planning of refurbishment and retrofit measures. Hence, benchmarks can be derived for the building performance as an indicative information for the portfolio analysis. With this systematic procedure a significant step toward a comprehensive building performance evaluation regarding sustainability is initiated. Another result is a praxis-oriented method for the evaluation of the sociocultural dimension in accordance to the criteria of the German `Sustainable Building´ Quality Label.

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