Workplace occupant satisfaction - a study in sixteen german office buildings

E. Gossauer [1)]; R. Leonhart[2)]; A. Wagner[1)]

1) Division of Building Physics and Technical Building Services
University of Karlsruhe, Englerstrasse 7, D - 76131 Karlsruhe, Germany

2) Department of Social Psychology and Methodology
University of Freiburg, Engelbergerstr. 41, D - 79085 Freiburg, Germany

ABSTRACT

This paper presents results of an evaluation of workplace occupant satisfaction in 16 office buildings in Germany. They were obtained in field surveys by means of a questionnaire and accompanying measurements in connection with an analysis of the architecture and the energy concept of the buildings. This paper mainly focuses on thermal comfort - in particular on the satisfaction of perceived room temperatures and its influencing factors such as measured daily room temperatures, indoor air quality, and humidity. Differences between winter and summer opinions and between the surveyed buildings have been analysed.

This paper also introduces a method that facilitates evaluating the potential of optimising building operation by means of occupant surveys and its relation to the general satisfaction within the workplace. In order to rank different satisfaction parameters for a more straight-forward building operation assessment, the weighted importance of every satisfaction parameter was calculated in relationship to the general acceptance of the workplace. In this case the satisfaction with the room temperature was evaluated.

KEYWORDS

Occupant satisfaction, satisfaction parameters, thermal comfort, post occupancy evaluation

INTRODUCTION AND OBJECTIVES OF THE STUDY

Comfort and well-being are not only very important for every individual for physiological and psychological reasons, but also play a significant role economically, as they strongly influence workplace productivity. Since personnel costs dominate all other costs, including building operation by two orders of magnitude, appropriate workplace conditions are of utmost importance for the economic success of companies. However, comfort issues do not play a major role in the day-to-day operation of commercial buildings, mostly due to a lack of understanding of human comfort and its on-going assessment.

The scientific community on the other hand has been accumulating knowledge on comfort in indoor environments for decades and the most important findings are now the basis of national and international standards and codes [1]. Most of the experiments, either performed in the lab or in the field, focused on correlations for single comfort criteria [2] or on health issues like the Sick-Building-Syndrome [3]. Fewer publications can be found on the interrelationships between different indoor environmental parameters and the significance of individual satisfaction parameters on well-being or the general satisfaction with respect to one’s a workplace. However, combined with monitoring of the engineered systems of a building, subjective occupant surveys have a large potential to improve workplace quality and effect energy savings if they are statistically proven [4, 5].

The aim of this work is therefore to evaluate the degree of general occupant-satisfaction with ones’s workplace as well as the occupants' rating of different individual satisfaction parameters in a variety of office buildings and to see whether a “satisfaction-index” can be created. Occupant satisfaction, and not just acceptance, in the context of this study is defined as the personal contentment with the thermal, visual and audible environment, the air quality at the workplace and the office layout. In this paper, these are referred to as "individual satisfaction parameters". The dependencies between these parameters are evaluated, both in their entirety and in connection with the buildings' architecture and energy concept.

Another objective of this evaluation is to determine, whether there are significant differences of the individual satisfaction parameters between the buildings, which allow for general conclusions with respect to energy-efficient design features. This is also true for differences between votes cast in summer and in winter. In this context, the question arises, whether it is possible to “group” buildings by the occupants’ ratings and if there is an interrelationship between the building’s energy and the architectural concept.

Furthermore, it is of great interest, which importance the individual satisfaction parameters have for the occupants and with which sensitivity they affect the well-being and the general acceptance of the workplace.

The surveys were conducted in 16 office buildings of a variety of sizes and energy concepts. Some of the buildings feature very low total energy consumption as well as passive cooling strategies [6, 7, 8].

METHOD

For the study, an existing questionnaire, originally developed at the University of California, Berkeley, was modified and pre-tested with about 100 persons in three different buildings. The questionnaire had been previously adapted for the project "enerkenn" [9], in which nine office buildings of the Track Infrastructure Stock Corporation of the German Railway Company (DB Netz AG) were evaluated.

In the questionnaire, all relevant aspects concerning occupant satisfaction of indoor environments are addressed. The questions adress properties directly related to the workplace including air quality, temperature, air velocity, humidity, acoustics and lighting. In addition, more general questions including office layout, well-being at work, general health as well as work related factors, such as the amount of work, communication between building occupants and the general acceptance of the workplace are raised as well. Questions are answered within a 5-point Likert-scale by the participants, but space for comments is provided as well. A copy of the presently used questionnaire can be found in [10].

Since January 2004 approximately 1300 questionnaires from 16 office buildings across Germany have been evaluated. In each building, the survey was carried out in winter and in summer in order to take into account the influence of diverse climate conditions on the occupants' judgement, particularly the temperature and the lighting rates. The survey has been carried out anonymously with a random sample size of 30 to 100 persons per building (depending on the size of the building). A return rate of more than

80 % was achieved on average by handing out paper questionnaires personally to the participants.

Additionally, room temperatures and humidity were measured with portable data loggers on the day of each survey. In some of the buildings, more data (e.g. continuously logged room temperatures, opening times of windows, indoor air quality etc.) are available from monitoring campaigns and will be used for the further evaluation.

The analysis of the occupants' responses was conducted with the statistical software program SPSS (Statistical Packages for the Social Sciences, Version 11.5 and 13.0). It includes the calculation of mean values, frequency distributions and correlation values as well as a regression analysis for dependent factors. Furthermore the correlations between independent factors were considered, for example between the general satisfaction and the individual satisfaction parameters. To identify significant differences in the ratings between summer and winter, an analysis of variance was carried out [11, 12]. The hypotheses were statistically tested with a two-tailed alpha level of 0.05; the different sample sizes and the occasional imparity of variance have been considered as well [13]. A cluster-analysis was used to identify possible groupings of building characteristics [14].

For the evaluation, to which extent the individual satisfaction parameters influence the general judgement of the workplace, the parameters can be correlated with the general satisfaction of the workplace. This leads to weighted values of the importance of each parameter in relation to the general satisfaction. This weighting procedure proved to be more reliable compared to the occupants' judgement, because occupants mostly tend to choose the categories "important" or "very important" if asked directly.

To illustrate the procedure of evaluation, the following survey-questions on "thermal comfort" were chosen:

1) How do you perceive the room temperature at the moment?
2) How did you perceive the room temperature in the mornings during the last two weeks?
3) How did you perceive the room temperature in the afternoons during the last two weeks?
4) How strongly did you perceive temperature changes at your workplace during the last two weeks?
5) How often did you attempt to change your room temperature during the last two weeks?
6) How satisfied were you with the effectiveness of the attempted temperature change(s) during the last two weeks?
7) **How satisfied were you all in all with the room temperature at your workplace during the last two weeks?**

RESULTS

In Figure 1 the mean values of the satisfaction with the room temperature in summer and winter are shown for each surveyed building. The results were calculated with data from the surveys that took place in winter 2004 and 2005 and summer 2004 and 2005.

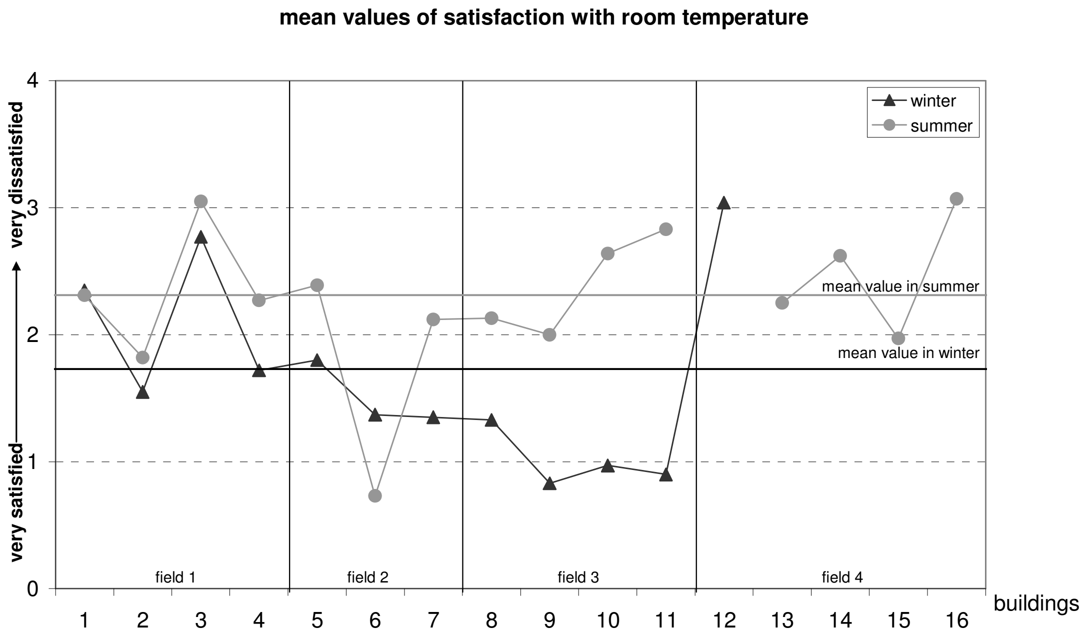

Figure 1: Mean values of the satisfaction vote with the room temperature during four survey periods (2 in winter and 2 in summer). Where available, the summer and winter ratings are combined. In field 1 there is no significant difference in the satisfaction with temperature between summer and winter ($p > 0{,}05$). In field 2 and 3 there is a significant difference between summer and winter ratings (field 2: $p = 0{,}02 – 0{,}04$; field 3: $p \leq 0{,}001$). In field 4 possible differences still have to be confirmed by the results of the winter survey in 2006.

In summer, the mean satisfaction with the room temperature is about 0.6 scale points below the mean satisfaction in winter. In summer, the mean ratings range from "moderately satisfied" to "dissatisfied" regarding the perceived room temperature, whereas in winter the ratings range from “satisfied” to “moderately satisfied”. In four buildings there does not occur a significant difference between the seasonal ratings. There are also significant differences between the mean ratings of all buildings ($p \leq 0{,}001$).

The differences were calculated with a t-test for independent samples for each building between summer and winter surveys with a two-tailed alpha-level of 0,05. This included the Levene-Test for parity of variance. Building No. 6 is the only one in which the mean rating of the summer temperatures was better than the winter rating. It is considered an outlier, which is further considered in the context of the cluster analysis.

In Figure 2, the perceived room temperature (too cold, cold, neutral, warm, too warm) is combined with the daily measured room temperatures. It can be seen that in winter (black triangles) the regression line intersects the neutral line at almost 23 °C which is almost one degree above the mean recommendation of ISO 7730 for room temperatures in winter. In summer it intersects the line at 23,5 °C which is one degree below the mean recommendation of ISO 7730 for room temperatures in summer. The measured daily values serve as a first orientation and as a good comparison between the buildings since long term measurements are still not available for more than half of the buildings. Future research will consider, if there is a significant difference between the two regression equations.

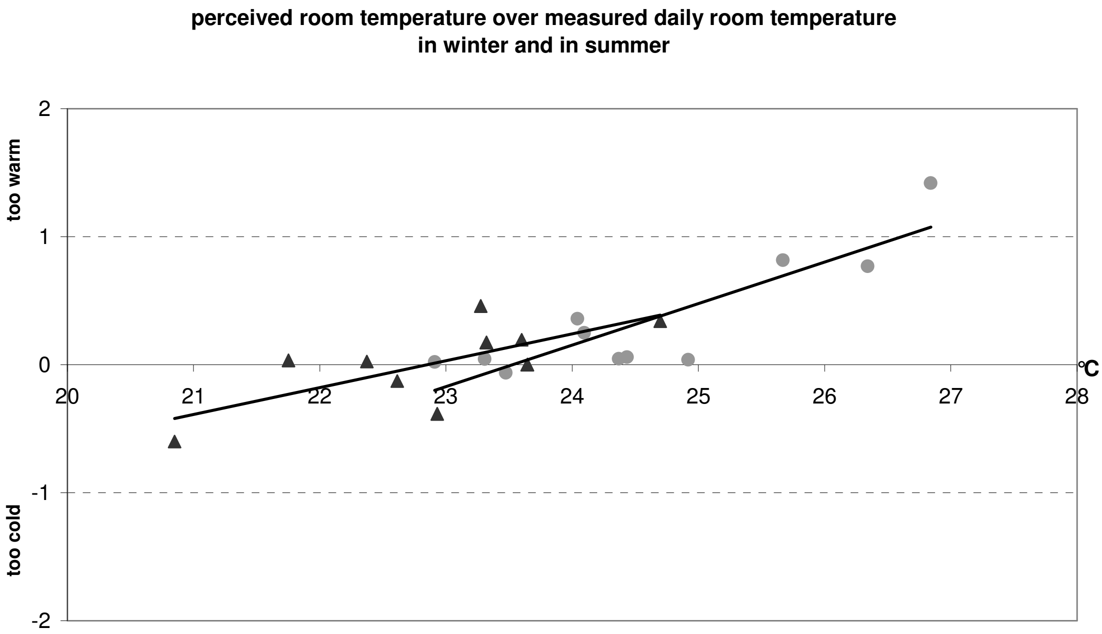

Figure 2: Temperature rating over measured room temperature (mean values of six rooms between 10 am and 3 pm on the day of the survey) in winter (black triangles) and summer (grey spots).

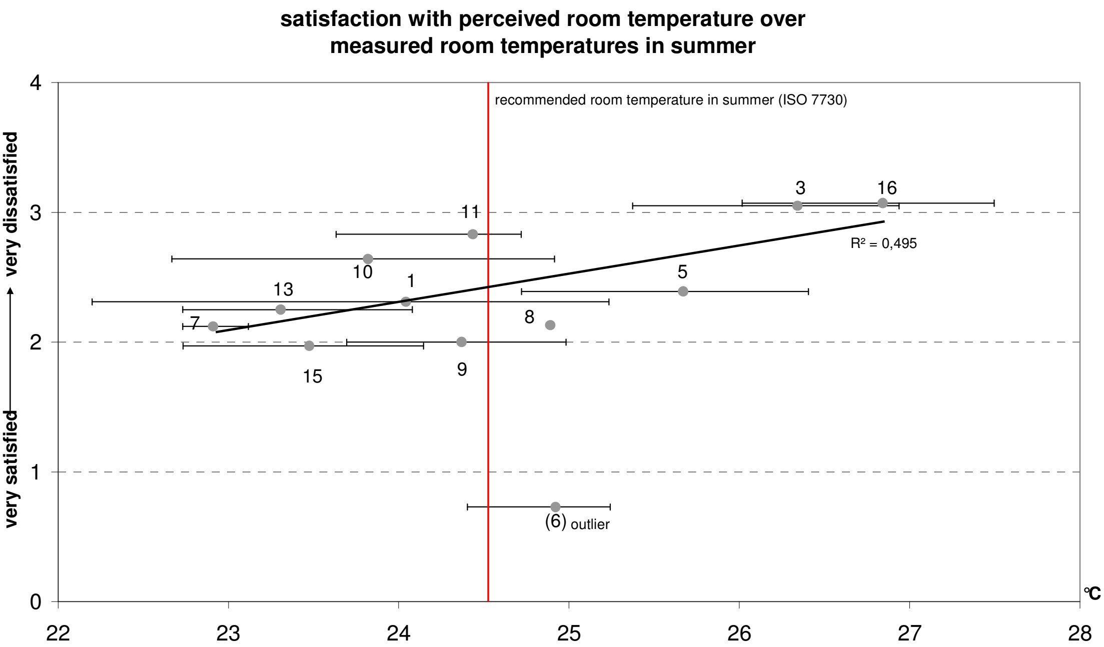

Figure 3: Mean satisfaction vote with respect to room temperature in summer versus the measured room temperature (mean value of six rooms measured between 10 am and 3 pm on the day of the survey).

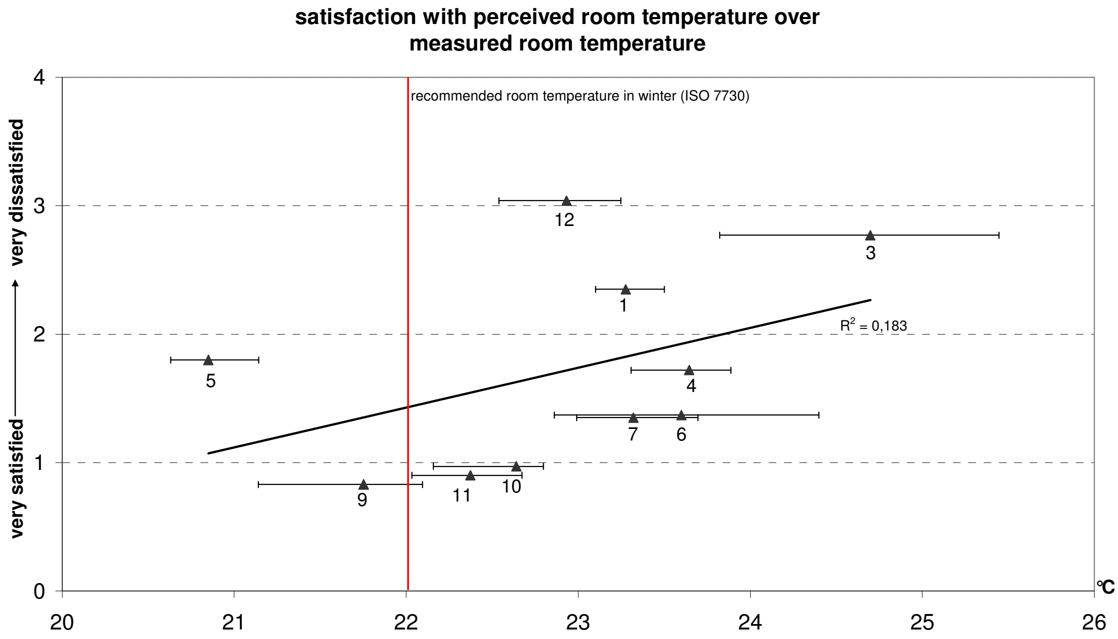

Figure 4: Satisfaction Vote with respect to room temperature in winter over the measured room temperature (mean value of six rooms measured between 10 am and 3 pm on the day of the survey).

Figures 3 and 4 show the connection between the satisfaction with the room temperature and the measured room temperatures in summer and in winter. It is evident, that with rising room temperature the satisfaction of the occupants is mainly decreasing.

What seems surprisingly is, that with similar room temperatures, those between 23 and 24 °C, the general satisfaction of the perceived room temperature in winter is higher than in summer. In winter 54 % of the occupants in all surveyed buildings are “very satisfied” or “satisfied” with the room temperature and in summer only 30 %.

In the winter surveys the satisfaction with temperature often corresponds with the sensation of being "too cold" and the feeling of draft. In summer the satisfaction with the room temperature is mostly associated with the sensation of being "too warm" as well as with dissatisfaction of the indoor air quality. Furthermore the ratings for fatigue correlate with the perception of room temperatures that are “too warm” and the self assessed disturbance of job performance.

A stepwise regression analysis with all temperature related variables showed, that in winter first of all the satisfaction with the effectiveness of attempted temperature changes, but also the perceived dryness of the air play a significant role in the general satisfaction with the room temperature. In summer most notably, too, the satisfaction of the effectiveness of attempted temperature changes, but also the perceived indoor air quality have the greatest effect on the satisfaction with the room temperature.

This means, that even more than the perceived temperature (too cold, too warm), the number of attempts to change the room temperature and the perceived changes or in a broader sense the ability to influence the room temperature, shows a strong influence on the occupant satisfaction. Therefore the greater dissatisfaction in summer could amongst others be explained with the reduced ability to take influence in the room temperatures or a less positive response on that. This still needs to be confirmed by analyzing the differences between the buildings with high and low controllability of the indoor climate by the occupants during winter and summer surveys.

The perception of humidity, especially in winter has a high and significant effect on the ratings of satisfaction with room temperature and perceived indoor air quality, but a very low one in summer. By correlating the measured mean values of relative humidity (as well as absolute humidity) and the occupant's ratings of perceived humidity, there is no dependence evident.

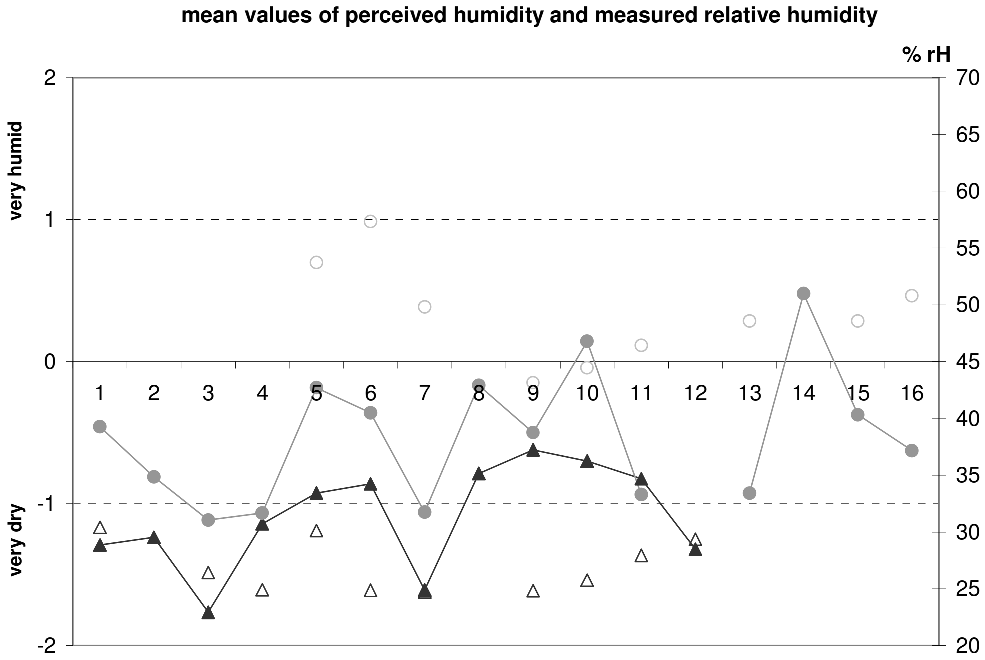

Figure 5: Perceived humidity together with measured relative humidity (mean values of six rooms measured between 10 am and 3 pm on the day of the survey).

It is remarkable, that the perception of the indoor air quality does not depend significantly on the seasons in most of the buildings (see Figure 6). Moreover, only a weak correlation with perceived odours can be observed.

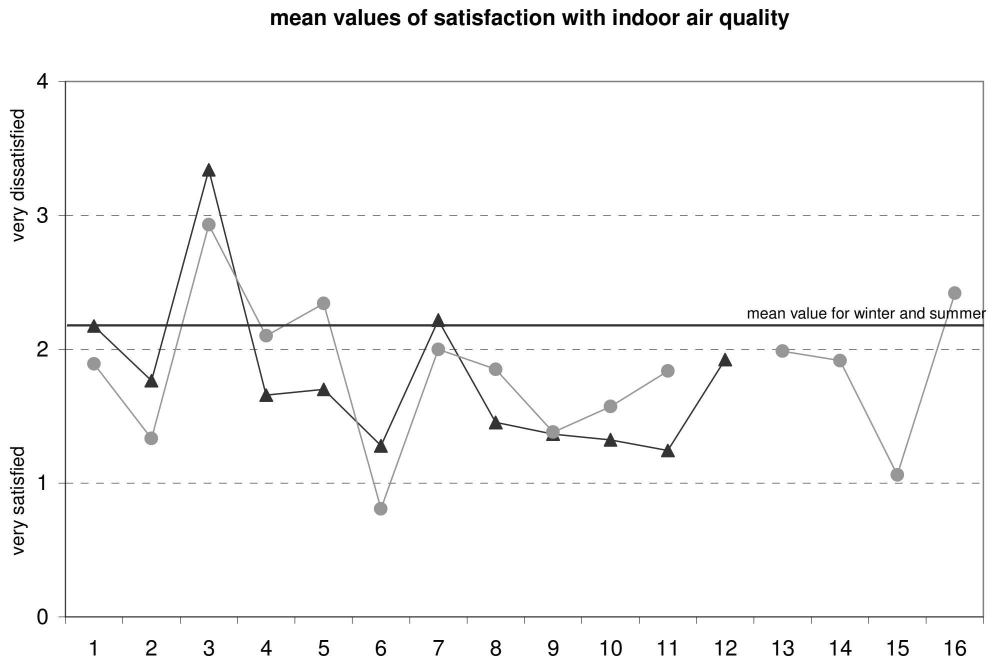

Figure 6: Mean values of satisfaction with the indoor air quality in summer (grey spots) and in winter (black triangles).

There is a noticeable difference in the correlations between the indoor air quality and the perception of humidity between winter and summer ratings. In winter the indoor air quality is mostly related to the perception of dry air. In contrast, in summer the indoor air quality is mostly related to the satisfaction with the room temperature and therefore perceived high temperatures.

To see, whether it is possible to group the buildings according to the occupants' contentment, a hierarchical cluster analysis was chosen. This analysis is conducted for each subject, since a building, that performs well concerning noises and office layout, must not necessarily be satisfactory with respect to temperature and indoor air quality. The cluster-analysis, that was calculated for the summer surveys, includes the following variables:

- current perception of room temperature,
- perception of room temperature in the mornings,
- perception of room temperature in the afternoons,
- perception of temperature changes,
- frequency of attempted temperature changes,
- satisfaction with effectiveness of attempted temperature changes,
- general satisfaction with room temperature,
- satisfaction with indoor air quality,
- fatigue and lack of concentration,
- dry nose, dry eyes.

Based on the above referenced variables, the following scheme has resulted:

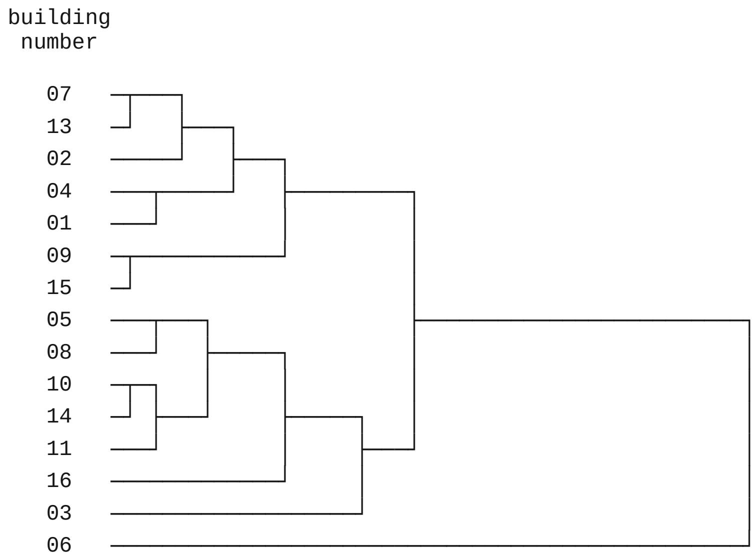

Figure 7: Dendrogram employing average linkage (between groups).

It can be seen, that there are linkages between some of the buildings, especially between the first seven listed buildings. A second group of another six buildings can be chosen. Buildings no. 03 and 6 cannot be linked with the other buildings. This confirms that before any other conclusions can be drawn, especially building no. 6 must be considered unique at least concerning the questions reagrding thermal comfort.

Table 1: Energy concepts of the clustered buildings and assumed linkages between them.

energy concept	**07**	**13**	**02**	**04**	**01**	**09**	**15**	**05**	**08**	**10**	**14**	**11**	**16**	**03**	**06**
nat. ventilation	(x)	x	x	x	(x)	x	x	x	x	x	x	x	x	(x)	x
night ventilation		x					x	x	x	x	x			x	x
supply air	x	x		(x)	(x)				x		(x)		(x)		x
exhaust air	x	x		(x)	(x)			x	x	x	(x)		(x)	x	x
air-humidifying	x				(x)										
radiator	x	x	x		(x)	x	(x)	x	x	x	x	x	x	(x)	
TABS	x	x	x		x									x	x
atrium	x	x	x		x		x								
double facade			(x)		x									x	
suspended ceiling				(x)		(x)					(x)				
glazing proport.	55%	35-65%	60%		90%		26%	35%	40%	30%		40%		90%	23%
glare protection	i	i	a	a	z	a	a	a	a	a	a	a	(a)	z	i
free-running		x	x	x		x	x	x	x	x	x	x	x		
partly air-cond.					x							(x)		x	x
fully air-cond.	x														

It is evident, that the clustering of the buildings, according to the mean values of the surveyed variables (temperature, indoor air quality, self-assesed fatigue and lack of concentration), is reflected in the comparison of the energy concepts.
The first group (light grey) represents those buildings with a medium to high glazing fraction. In four of them a TAB-systems is installed. Five of the buildings of this group have a large number of offices that are adjacent to an atrium. It still has to be investigated, in which way this feature can be used qualitatively for the evaluation. The buildings from the second group (dark grey) partly share the feature of night-time-ventilation and intermediate glazing fractions. The last two buildings have a completely different architectural concept. No. 3 has a double façade and a very high glazing fraction. The satisfaction with the indoor climate is very poor due to difficulties in operating the HVAC systems and very warm temperatures in the offices especially on sunny winter days. Building no. 6 satisfies the passive house standard and features a low glazing fraction for an office building. The satisfaction in this building is very high due to very effectively operated building systems. Temperatures are moderate even on bright summer days.

An explorative approach by means of a discriminant analysis revealed, that the greatest difference between the clustered buildings can be found within the mean vote of the perceived temperature in the mornings (see figure 8). Buildings from the first group perceive the room temperature as more or less neutral. Buildings from the second group consider it to be “too”warm. There is almost no variance between the mean votes of the buildings within both clusters. The general satisfaction with room temperature is higher in the buildings of the first cluster. In regard to the variables about the perceived temperature, building no. 6 can be counted to the first cluster and building no. 3 to the second cluster. Building 3 and 6 are not part of the two clusters, because differences occur e. g. within the variables “perceived temperature changes” and “satisfaction with effectiveness of attempted temperature changes”.

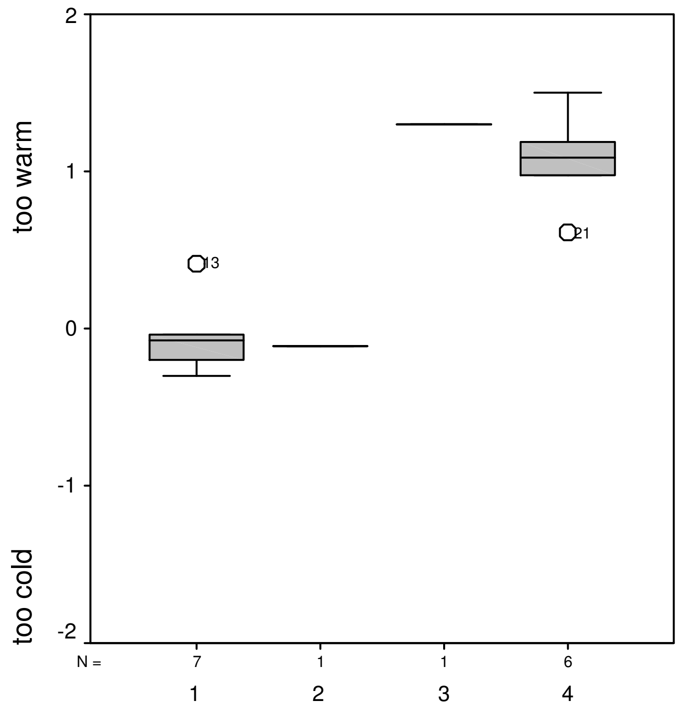

Figure 8: Average linkage (between groups) for the variable “perceived room temperature in the mornings”.

A more detailed analysis of the differences and similarities in the building concepts will be considered in a follow-on study of this research.

Looking at the impact of the satisfaction with the room temperature on the general satisfaction with the building, there appears to be inconsistency among the buildings as well as between summer and winter surveys. Because the correlation between the satisfaction-parameters and the general satisfaction with the workplace often varied drastically from building to building, a scale is introduced, which includes the following parameters:

- satisfaction with daylight
- satisfaction with artificial light,
- satisfaction with room temperature,
- satisfaction with indoor air quality,
- satisfaction with noises,
- satisfaction with office layout and
- satisfaction with cleanliness of the office.

The reliability of the scale was tested with Cronbach's alpha coefficient and showed, that the single parameters can be combined completely. The scale also reflects the general satisfaction with the workplace very well: The correlation coefficient (Spearman) between the scale value and the general satisfaction with the workplace is 0,685 ($p \leq 0,001$).

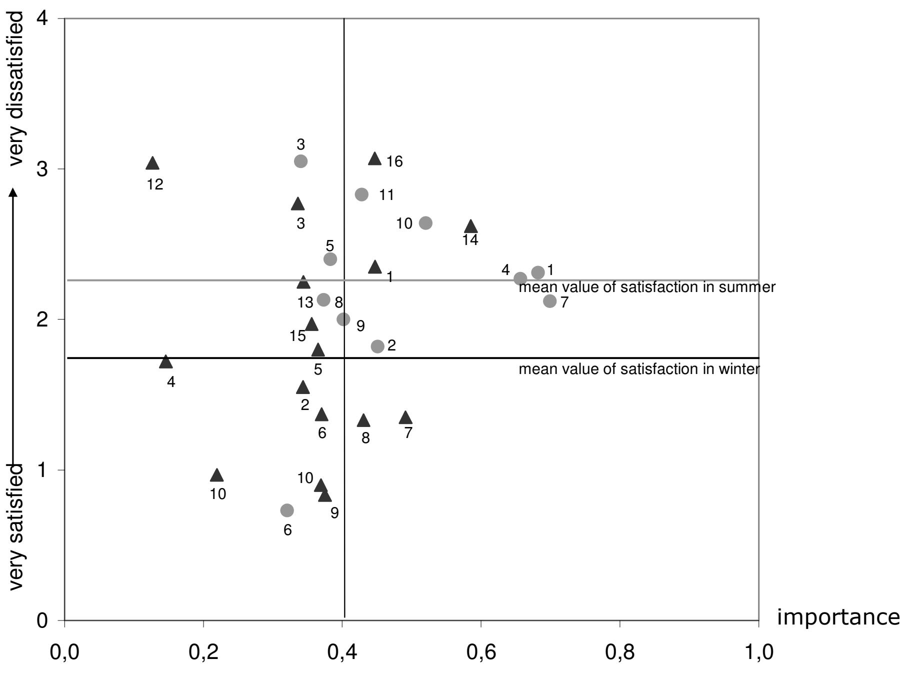

Figure 9: Correlation between mean satisfaction with the temperature and weighted importance of the temperature for the general satisfaction with the workplace (Spearman correlation). Field A: occupants are satisfied with the parameter but the weighting calculation shows that it is less important for the general satisfaction with the workplace. Field B: occupants are satisfied with the parameter and it is important for the general satisfaction with the workplace. Field C: occupants are dissatisfied with the parameter but it is of less importance for the general satisfaction with the workplace. Field D: occupants are dissatisfied with the parameter and it is very important for the general satisfaction with the workplace.

Though the scale is a very good indicator fort the overall satisfaction, individual subjects in each building affect the general level of satisfaction the most. Figure 8 gives an example of using surveys for the assessment of building operation. It shows the satisfaction with the temperature together with its weighted importance for the general satisfaction with the workplace.

In particular the buildings that are situated in field D call for action concerning the thermal comfort at the workplaces, because the occupants are dissatisfied with the prevalent temperatures and the temperature is weighted as rather important for the general satisfaction with their workplace. This might affect their productivity. The diagram shows, that in summer (grey spots) the importance of an adequate room temperature and the ability to take influence in it is more important for the general satisfaction than in winter. In buildings of field C a great dissatisfaction with the room temperature can be found in winter and summer. While the dissatisfaction in these buildings also implicates a great potential for improvements, other parameters seem to be more important for the general satisfaction with the workplace, as for example the office layout and interferences because of noises.

Buildings in fields A and B are not critical with regard to the parameter "satisfaction with room temperature", because the occupants are rather satisfied on average. In some buildings the parameter influences the judgement of the general satisfaction positively. The positive judgements come almost exclusively from the winter ratings – except No. 6 which was discussed before.

CONCLUSION AND OUTLOOK

Though most of the evaluated buildings showed room temperatures in the comfort range of ISO 7730 in summer, only 30 % of all occupants were satisfied or very satisfied with the room temperatures in their offices. Since both air humidity and air quality are evaluated similar in winter and in summer and the correlations between summer and winter surveys differ, other parameters concerning the general comfort cover the satisfaction with thermal conditions.

Obviously, the sensed occupants' control is limited in summer. For example, since the temperature difference between inside and outside is smaller, the manual control of windows changes the room temperature not as strong as in in winter and therefore the occupants sense their interaction less. This does not imply that the occupants automatically accept higher temperatures but are rather dissatisfied even with moderate room temperatures. More research is necessary to investigate this correlation between measurements and surveys and to get more conclusions about the connection with the energy and architectural concepts.

By correlating the individual satisfaction parameters with the general satisfaction with the workplace, a weighted importance for each parameter can be gained. This method of ranking the individual satisfaction parameters provides a more straight-forward assessment of building operation by showing the optimisation potential for each comfort parameter. In combination with the mean values of the satisfaction parameters the need of (urgent) changes in the building and the possibilities to raise the occupants' productivity becomes transparent for the building manager. This includes not only the operation of the technical systems but also the accordance of the occupants' behaviour with the specific building concept. By comparison of the mean values and variances of the satisfaction parameters between the buildings, it still has to be ascertained, where the borders of the satisfaction fields will be situated finally.

The large variety of architectural and technical concepts for buildings does only allow a qualitative evaluation of the effect on the occupant-satisfaction at the moment. Further evaluations of the data gained in the surveys will concentrate deeper on the question, whether certain energy-conscious design features show the intended positive effect on the occupants with statistical proof. This includes investigations to what degree occupants are normally dissatisfied with certain parameters and to what extend factors like gender, job structures and others cover architectural influences.

ACKNOWLEDGEMENT

This study is funded by the German Ministry of Economics and Labour (BMWA) within the programs EnBau:Monitor and EVA [15].

REFERENCES

1. prEN ISO 7730:2005, Ergonomics of thermal environment, Beuth Verlag, 2005
2. deDear, R.J., Brager, G.S.: Thermal Comfort in naturally ventilated buildings - revisions to ASHRAE Standard 55, Energy and Buildings 34, 2002
3. Nicol, F.; Humphreys, M.: Adaptive thermal comfort and sustainable thermal standards for buildings, Energy and Buildings, 34 (6): 563-572, 2002
4. Bischof, W.; Bullinger, M.; Kruppa, B.; Müller, B.; H.; Schwab, R.: Expositionen und gesundheitliche Beeinträchtigungen in Bürogebäuden, Ergebnisse des ProklimA-Projektes, Fraunhofer IRB Verlag, 2003
5. deDear, R.J., A global database of themal comfort field experiments. ASHRAE Transactions SF-98-11-1 (RP-884), 1998
6. Pfafferott, J; Enhancing the design and operation of passive cooling concepts, Fraunhofer IBR, 2004
7. Plesser, S.; Bremer, C. ; Fisch, M. N.; "EVA – Forschungsprojekt zur Evaluierung von Energiekonzepten III: Auf dem Prüfstand V – Bürogebäude Neumühlen 4" In Intelligente Architektur 53; Verlagsanstalt Alexander Koch GmbH, Leinfelden-Echterdingen, 2005
8. Plesser, S.; Gerder, F.; Bremer, C.; Fisch, M.N.; "EVA – Forschungsprojekt zur Evaluierung von Energiekonzepten IV: Auf dem Prüfstand – Neubau Informatikzentrum der TU Braunschweig." In Intelligente Architektur 51; Verlagsanstalt Alexander Koch GmbH, Leinfelden-Echterdingen, 2005
9. Froehlich, S.; Wagner, A.; Wambsganß, M.; Schlums, M.: ENERKENN - Web-based Method to generate specific Energy Consumption Data for Evaluation and Optimization of Office Building Operation, Proceedings of EPIC 2002 AIVC Conference, Lyon, October 2002
10. Voss, K.; Herkel, S.; Löhnert, G.; Wagner, A.; Wambsganß, M.: Bürogebäude mit Zukunft - Konzepte, Erfahrungen, Analysen, TÜV-Verlag, 2005
11. Bortz, A.; Döring, M. : Grundlagen der Evaluation und Datenauswertung. Masson, Paris, 1955
12. Brosius, F.: SPSS 12; MTP Verlag, 2004
13. Hays, W.L., Statistics (5 ed.), Forth Worth: Harcourt, 1994

14. Hair, J.F., Anderson, R.E., Tatham, R.L. & Black, W.C., Multivariate Data Analysis, Upper Saddle River, New Jersey: Prentice Hall College Div., 1995

15. Plesser, S.; Bremer, C.; Fisch, N.: "EVA – Forschungsprojekt zur Evaluierung von Energiekonzepten: Auf dem Prüfstand.", Intelligente Architektur 43, Verlagsanstalt Alexander Koch GmbH, Leinfelden-Echterdingen, 2003