Proceedings of Conference: ***Air Conditioning and the Low Carbon Cooling Challenge***, Cumberland Lodge, Windsor, UK, 27-29 July 2008. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk.

Occupant satisfaction at workplaces – a field study in office buildings

Elke Gossauer, Andreas Wagner

Building Science Group, University of Karlsruhe, Englerstr. 7, D - 76131 Karlsruhe, Germany, info@fbta.uni-karlsruhe.de

Abstract

By applying multivariate analysis to survey data of a field study in 17 buildings, several correlations between different parameters with regard to satisfaction at workplaces could be found and validated. A significant difference between winter and summer votes on the satisfaction with the indoor temperature could be shown; the dissatisfaction at neutral thermal sensation was considerably higher in summer. In total, only 30% of the occupants were very satisfied or satisfied with the temperature at their workplace in summer and winter. In most of the buildings momentary votes on thermal sensation appeared to be more positive than retrospective votes. The perceived effectiveness of attempted temperature changes proofed to be the dominant parameter for the satisfaction with the indoor temperature.

By weighting single satisfaction parameters a matrix could be generated which provides a straight-forward assessment of building performance by showing the optimisation potential for each parameter and the necessity to act for the building manager.

Keywords

Occupant satisfaction, thermal comfort, POE

Introduction

The introduction of the European Directive on Energy Performance of Buildings will have a significant influence on future building and energy concepts. Due to the progressive limitation of the total energy consumption of buildings in the EU by national standards, passive or hybrid cooling strategies based on natural heat sinks will more and more attract notice of architects and planners in the future. Even today, a large number of very good built examples exist with monitoring data and performance experiences available, e.g. [1].

Despite the advantages of these buildings with "lean" technical equipment regarding investment and operating costs, the requirements for workplaces in terms of thermal comfort, air quality etc. have to be met without exemptions. They are the basis of the occupants' satisfaction and their productivity, which are both important economical factors. Personnel costs dominate all other operating costs by far. Therefore, aspects regarding comfort and occupant satisfaction have to be taken into account equally during building design and operation compared to questions about energy efficiency.

In practice, only little attention is given to these topics so far. Different surveys with scientific background have been carried out since the nineties to find correlations between different building parameters and comfort, health and productivity, e.g. [2], [3], [4], [5]. Still a large number of these interrelations are not known today and further research is needed. On the other hand, practicable methodologies and tools are necessary to implement POE in the everyday building management in order to optimise building operation. This study which reports on a survey in 17 German office building is a step into both directions, enhancing the knowledge about occupant satisfaction and relevant influencing parameters as well as to provide a concept for introducing POE into the practice of facility managers.

With green or sustainable building labelling and certification becoming more and more popular on an international scale, POE might gain a higher relevance in the context of building stock evaluation and management. Besides economical and ecological characteristics further occupancy-related criteria have to be taken into account in order to provide a complete assessment of a building in terms of sustainability. For this, the subjective rating of occupants and its statistical analysis is the only way to get information about the occupants' perception of the building performance. To allow a systematic benchmarking or rating of buildings, indicators – or probably one overall indicator – have to be developed out of the POE results which are completing the picture of sustainability for the social component.

Methodology

The whole study was carried out between January 2004 and September 2007. Approximately 1500 questionnaires from 17 buildings were evaluated together with measured data – indoor temperatures and humidity from portable data loggers – which were taken during the surveys. In each building, a winter and a summer survey was carried out in order to take into account the influence of diverse climate conditions on the occupants' judgement, particularly the temperature and the lighting rates. Ttransverse surveys were conducted to exclude memory effects of the occupants. 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).

For the study, a questionnaire which originated at the University of California's Centre of Environmental Design Research, Berkeley, was modified and pre-tested with about 100 persons in three different buildings. In the questionnaire, all relevant aspects of occupant satisfaction with indoor environments are addressed. Occupant satisfaction in this case is defined by the occupants' ratings of thermal, visual and acoustic comfort, the indoor air quality and the office layout. The questions address properties directly related to the workplace such as 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 assessed as well. Questions are answered within a 5-point Likert-scale by the participants but space for comments is provided as well. More details of the questionnaire design and the experimental setup can be found in [6]. It is important to mention that the occupants were asked to evaluate the indoor conditions over a period of two weeks retrospectively to the day of the survey. This period was chosen as a trade-off between a reasonable time span for the occupants' retrospection ability and a sufficient number of days on which the occupants were present at their workplaces.

The analysis of the occupants’ responses was conducted with the statistical software program SPSS (Statistical Packages for the Social Sciences, Versions 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. Different types of scales (uni-polar, bi-polar) were correlated by appropriate coding [6]. To identify significant differences in the ratings between summer and winter, an analysis of variance was carried out. A cluster-analysis as well as a discriminant analysis was used to identify possible groupings of building characteristics.

Results and Discussion

Climate conditions during the surveys and representativeness of the periods chosen

One hypothesis of the study was that there are differences in the occupants' ratings between winter and summer, particularly regarding thermal comfort and daylighting. Although this had been investigated in different studies before the focus here was on the influence of different satisfaction parameters in the two seasons. Therefore, two surveys were carried out in each building. Due to several circumstances – 6 to 7 surveys per season carried out one after another, different vacation periods in the different federal states of Germany – the total time span for all surveys of one seasonal set was rather long. In order to verify the climate conditions for the winter and summer surveys, an analysis of the outdoor temperature was carried out.

Figure 1 shows the daily means of the outdoor temperature for the different sites during the two weeks before the surveys. A clear difference between the winter and summer values can be seen and there is no overlap in the mean values. A winter day can be defined by the outdoor temperature under which heating is necessary. Due to the German standards this temperature is 10°C for highly insulated buildings. According to figure 1, all winter surveys (between January and March) met this criterion.

According to the meteorological definition for a summer day, only days with a maximum outdoor temperature of more than 25°C are counted. As the occupants were asked to evaluate the indoor conditions retrospectively, the climate data were tested against the following criteria: the maximum outdoor temperature had to be above 25°C either on 5 days over the whole regarded period or on at least 3 days immediately before the survey. The latter refers to a stronger personal weighting of the days closer to the survey with respect to the occupants' memories [7]. The analysis shows that only one survey (in building 15, August 2005) missed that criterion (figure 1).

Additionally, the occupants were asked whether they would personally rate the respective period as representative for the particular season considering the climate conditions. 80% of the occupants found that the period of the survey was representative for the winter season, and for the summer season 50% positive answers were counted. The difference proofed to be highly significant. The lowest agreement was found in the buildings 15 and 17 for the summer period (16% and 20%) which coincides with the temperature data in figure 1. This is also true for the buildings 9 and 13 with only approx. 30% positive answers with respect to the representativeness. It is also worthwhile to mention that in both seasons approx. 40% of the occupants (winter 44%, summer 36%) included memories from a longer period into their ratings, instead of only the last two weeks. An additional question on this topic was added to the questionnaire during the study.

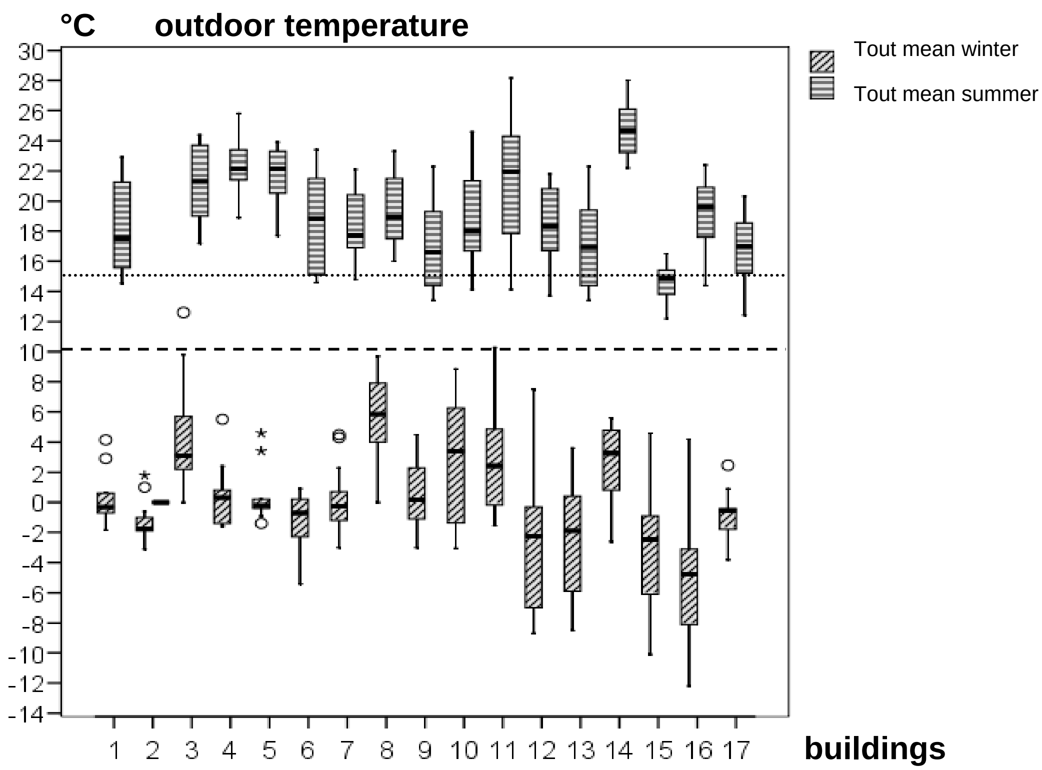

Figure 1: Box plot (median values of outdoor temperature over two weeks, 25th and 75th percentile as well as whole range) of daily mean outdoor temperatures over a period of two weeks before the surveys in the 17 buildings. The dotted lines represent the temperatures above which cooling is initiated in some buildings or under which heating is necessary in highly insulated buildings in Germany.

The results imply that it is more difficult to find representative periods for the summer season, particularly if longer time spans are chosen for the evaluation. Alternatively, surveys could be carried out more frequently only taking into account the actual day of the survey as a reference period. For that, questionnaires should be limited to thermal comfort issues.

Thermal sensation and satisfaction with indoor temperature

Questions with regard to thermal comfort included the thermal sensation (momentary / retrospective – morning, afternoon), the possibility to change indoor climate conditions, the perceived effectiveness of changes, the perceived humidity, the perceived air quality and the overall satisfaction with the indoor temperature. Besides the question on thermal sensation all other questions refer to a period of the two weeks prior to the survey. Correlations between the perceived indoor temperature and measured temperatures as well as between the satisfaction with the indoor temperature and measured data respectively were based on momentary ratings and corresponding measurements (day of the survey).

The analysis of the data confirmed the hypothesis that there is a significant difference between the winter and summer votes on the satisfaction with the indoor temperature. In summer, the mean satisfaction with the indoor temperature is about 0.9 scale points below the mean satisfaction in winter (summer: 2.3, winter: 1.4 on a 5-point-scale; 0 = very satisfied, 5 = very dissatisfied). The summer ratings range from "moderately satisfied" to "dissatisfied" with respect to the thermal sensation. In winter, the ratings range from "satisfied" to "moderately satisfied". In four buildings, no significant difference occurs between the seasonal ratings.

With regard to the thermal sensation significant differences ($p < 0.05$) between the momentary votes and the votes for morning and afternoon could be found for winter and summer. In most of the buildings the momentary votes appeared to be more positive than the retrospective votes ("negative retrospective effect" [8]). In figure 2 the correlation between the thermal sensation and the satisfaction with the indoor temperature is given for the winter season. Here it can be seen that the momentary votes on thermal sensation coincide with higher dissatisfaction rates compared to the retrospective votes. Obviously, further parameters had a stronger influence on the satisfaction besides the thermal sensation. The mean value of dissatisfaction (momentary and all retrospective votes) for the thermal sensation "slightly warm" is lower as the value for "slightly cold", suggesting that a slight shift of the thermal sensation to the warm side is better accepted than to the other side. The retrospective votes on the warm side are also closer together than those on the cold side. In total, a maximum of 80% appears "dissatisfied" and "very dissatisfied" in the categories "too warm" and "too cold".

Figure 3 confirms the higher dissatisfaction of the occupants in summer with a minimum for the momentary votes of 36% (compared to 10% in the winter). 353 out of 737 occupants chose the categories "dissatisfied" and "very dissatisfied" with the indoor temperature. For the retrospective vote "too warm" in the mornings there is a much higher percentage of dissatisfied compared to the vote "too cold" in the same period. For the afternoon votes it is just the other way round. The momentary votes are almost symmetrical. Obviously, a higher indoor temperature in the morning and lower temperature in the afternoon were perceived more unpleasant which might relate to expectations and adaptations with regard to the temperature change during the day.

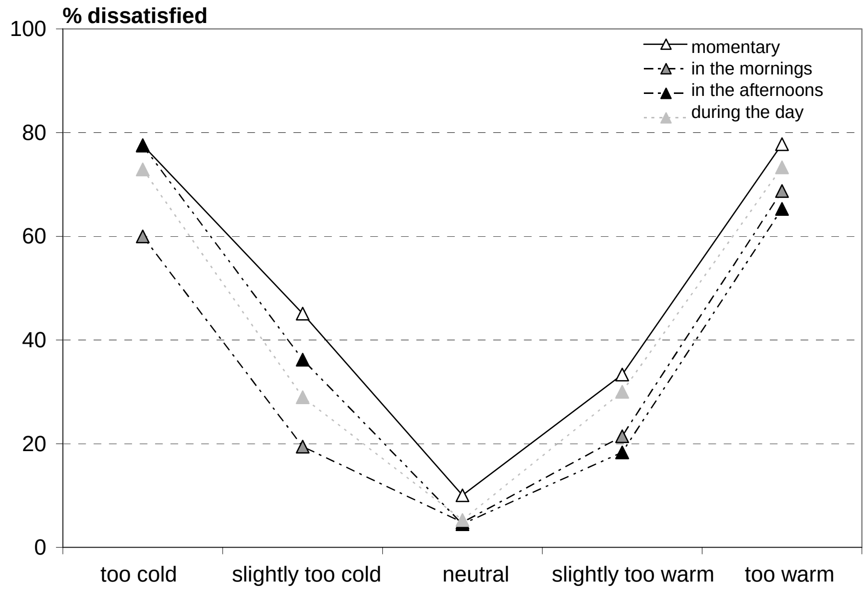

Figure 2: Correlation between the thermal sensation and the occupants' satisfaction with the indoor temperature ("dissatisfied" and "very dissatisfied", N = 198 out of 718 subjects) for the winter season

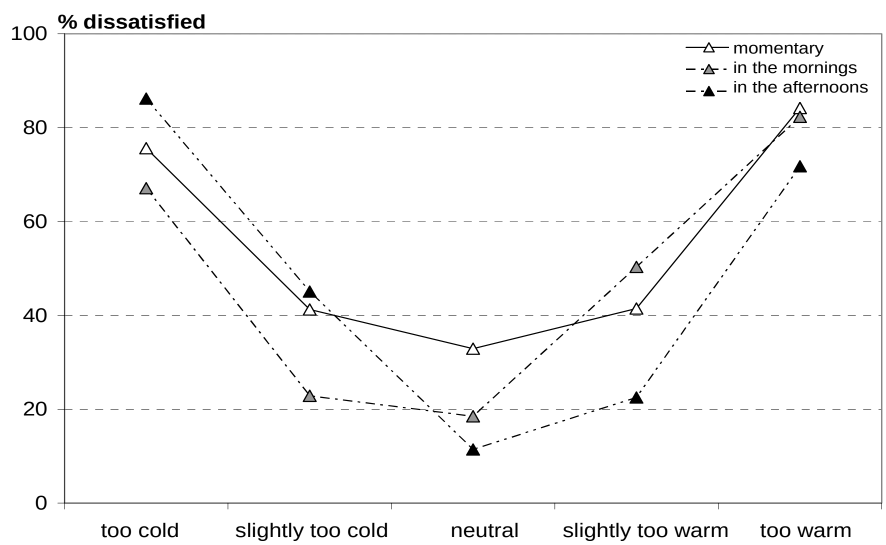

Figure 3: Correlation between the thermal sensation and the occupants' satisfaction with the indoor temperature ("dissatisfied" and "very dissatisfied", N = 335 out of 737 subjects) for the summer season

Further analysis revealed a significant difference ($p = 0.002$) between the thermal sensation of women and men in summer, mostly in the category "too cold" (only 10% of the male occupants voted "too cold" compared to 20% female occupants). Although the clo-values of the occupants could not be recorded it is assumed that the different clothing is mainly responsible for this result [9]. A subdivision of the buildings with regard to a given dress code confirmed that there was a significant difference ($p \leq 0.005$) in answering all questions related to thermal comfort during summer between women working in buildings with and without a dress code. In buildings with dress code the indoor temperature was normally perceived warmer and the satisfaction with the temperature was lower. According to that the number of attempted changes of the indoor climate was higher with a lower satisfaction with regard to the effect.

In figure 4 the mean values of the votes on the thermal sensation are given as a function of the measured indoor temperatures. The fitted temperature for the vote "just right" is almost the same for winter and summer (23.2°C and 23.5°C). The optimum (operative) temperatures in DIN EN ISO 7730 are 22°C for the winter season and 24.5°C for the summer season with 6% dissatisfied. For a percentage of dissatisfied of 15% a deviation of ± 2.5 °C is allowed. In figure 4 the slope of the regression curve for the summer votes is steeper compared to the curve of the winter votes. This probably indicates that lower temperatures are compensated with clothing in the winter season.

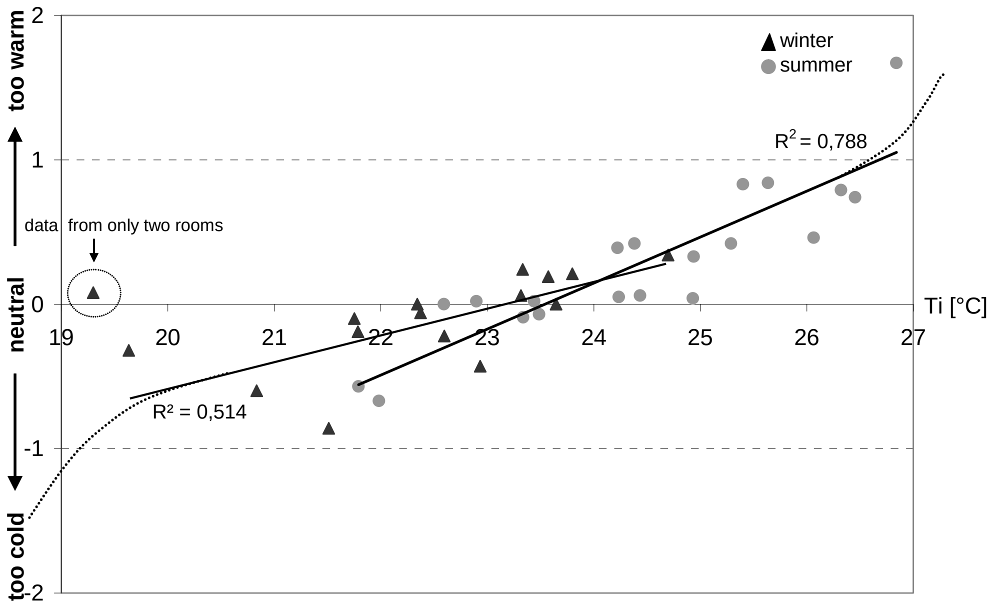

Figure 4: Mean values of the thermal sensation over mean values of measured indoor temperatures on the day of the surveys in winter and in summer

In summer the acceptable temperature range seems to be smaller: lower temperatures cannot be fully compensated by clothing and higher temperatures are perceived as too warm. The thermal perception in the investigated buildings seems to be close to neutral between 21.5°C und 24°C during winter and between 22°C und 25°C during summer. The reliability of these conclusions on the bases of measurements in 6 exemplary offices of a building is considerably higher for the summer (R^2 = 0,788) compared to the winter (R^2 = 0,514). This might be due to larger (user-induced) indoor temperature differences between the offices in winter which could not be considered appropriately by only six reference measurements.
The retrospective thermal perception showed a significant difference between the votes for the mornings and the afternoons for both seasons. Consequently, the momentary votes were also divided into a morning and an afternoon group according to the time of filling in the

questionnaire. Again, a significant difference in the votes can be seen ($p_{winter} = 0.037$, $p_{summer} \leq 0.001$). In the winter season, the mean vote on the temperature over all buildings was "slightly cold" in the morning and almost "neutral" in the afternoon. In the summer season, the mean vote was "slightly warm" in the morning and "rather warm" in the afternoon. The differences are smaller compared to the retrospective votes.

The measured temperatures on the days of the surveys show that the differences over the days were rather small: in the winter season the ΔT in the different buildings between morning and afternoon ranged from -0.31 K to +0.55 K and in the summer season from -0.11 K (air-conditioned building) to +0.9 K. Therefore it is assumed that there must be other reasons – e.g. expectations – for the different thermal perceptions in the morning and in the afternoon.

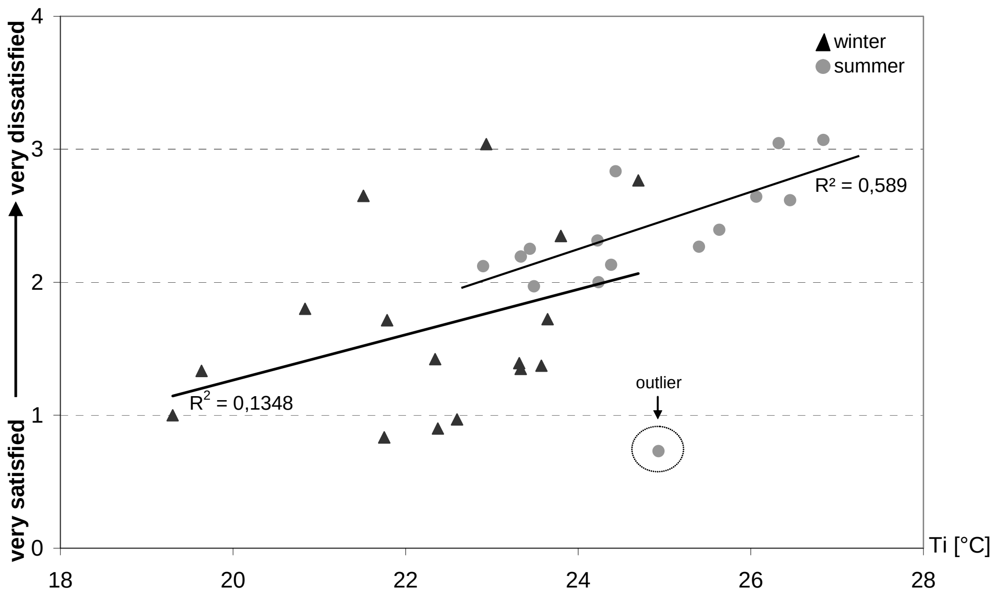

Figure 5: Mean values of the satisfaction with the indoor temperature over mean values of measured indoor temperatures in the buildings

The correlation between the satisfaction with the indoor temperature and measured temperatures in the buildings is given in figure 5. The linear regression gives a very weak prediction quality for the winter values and further data points – particularly at lower temperatures – are needed for a representative correlation. The prediction quality for the summer season is higher and it can be seen that in the overlapping temperature range the summer values indicate a higher dissatisfaction compared to the winter situation. Considering the temperature ranges of DIN EN ISO 7730 which give an acceptance of 85% between 19.5°C and 24.5°C in the winter season and between 22°C und 27°C in the summer season a considerably higher dissatisfaction can be seen in the survey results, particularly in summer.

Factors influencing the satisfaction with the indoor temperature

In the beginning of the study it was assumed that the thermal sensation has the strongest impact on the satisfaction with the indoor temperature but other factors have to be taken into account as well. This was investigated by a stepwise regression analysis that took into account all temperature related variables (see figure 6). A remarkable result which coincides with figure 4 (slope of curve for the winter votes) is that the perception of the indoor temperature has a negligible influence on the satisfaction with the indoor temperature in the winter season ($R = -0.17$; $p \leq 0.001$). In summer, this influence is stronger ($R = 0.42$; $p \leq 0.001$) but obviously this variable is not the most important one.

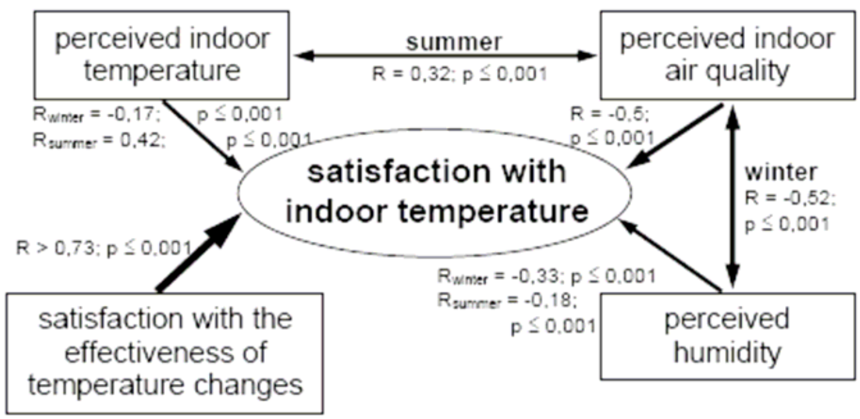

Figure 6: Influences and interrelations between different temperature related variables together with correlation coefficients of the stepwise regression analysis

Further, the votes on air quality show a moderate correlation with the satisfaction with the indoor temperature in both seasons ($R_{winter} = 0.47$; $p \leq 0.001$ / $R_{summer} = 0.52$; $p \leq 0.001$). Regarding parameters influencing the perception of air quality there is a distinct correlation with the humidity in the winter season ($R = -0.52$; $p \leq 0.001$) whereas during summer the perceived indoor temperature has the strongest influence ($R = 0.32$; $p \leq 0.001$). The perception of the humidity also has a significant influence on the satisfaction with the indoor temperature in the winter season ($R = -0.33$; $p \leq 0.001$). This means that occupants show a higher dissatisfaction with the air quality and the indoor temperature when the perception of the indoor air is dry which mostly occurs in winter. In summer, low air quality is often explained by high indoor temperatures.

The strongest correlation was found between the satisfaction with the indoor temperature and the perceived effectiveness of attempted temperature changes ($R_{winter/summer} > 0.73$; $p \leq 0.001$). This means that the occupants were more satisfied with the indoor temperature when they were able to influence the indoor climate and they could realize the result. These findings are in good accordance with various other studies. This also explains the higher dissatisfaction with the indoor temperature in the summer season (see figures 2, 3 and 5), because the possibilities for significant changes of the temperature are lower (in passively cooled and naturally ventilated buildings) due to higher outdoor temperatures. On the other hand this gives a clear hint to include possible interactions of occupants into the design of a building (openable windows. manually operable shading devices etc.).

The occupants' rating also allowed a subdivision of the examined buildings into actively cooled / air-conditioned and non-air-conditioned buildings. The temperatures in the non-air-conditioned buildings were perceived warmer and the mean satisfaction was lower – even if the measured temperatures were equal or at least similar to the temperatures in the other group of buildings. The best ratings were given to buildings with a hybrid concept which includes cooling (thermally activated concrete slabs) and allows an intervention of the occupants to change the indoor conditions.

Overall workplace satisfaction and relevant parameters

Besides thermal comfort other parameters were examined with regard to the satisfaction with the workplace and to seasonal differences. The votes on satisfaction with daylight and artificial light do not show considerable differences between winter and summer in the different buildings. One reason could be that the occupants did adapt to the changing conditions over the year. Further, the survey is probably not suited to address this field properly because of the high dynamics of daylight which cannot be evaluated precisely enough by the occupants with "integrating" retrospectively over a day or even two weeks. Also the votes on noise at the workplace and on the office equipment did not show seasonal differences which means that only thermal comfort has to be addressed seasonally.

Considering the design of (new) buildings, concrete measures could be derived from the statistical analysis, which lead to a higher satisfaction at the workplace:

- natural ventilation
- individual control on indoor temperature (in both seasons)
- differentiated design of workspaces
- small office units
- no offices adjacent to atria.

The analysed data show that particularly in cellular offices the satisfaction with the office equipment and with aural comfort was very high. In personal interviews occupants stated an office size up to a maximum of 4 persons as optimal. In small units like these the possibility to interfere with the indoor climate conditions – ventilation by opening the window, temperature control, operation of shading devices or adjusting artificial light – is much higher compared to larger units.

A further objective of the study was to identify the optimisation potential of the building performance by POE. By correlating the different individual satisfaction parameters with the overall satisfaction with the workplace a weighting of these single satisfaction parameters is possible. 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. The results for all parameters and all investigated buildings are shown in figure 7. The diagram reveals that the building standard of the investigated buildings was rather high (no parameters with low votes on satisfaction). Therefore, further surveys in buildings with a lower standard are necessary to adjust both scales. In figure 7 the mean values have been taken to subdivide the field of parameters.

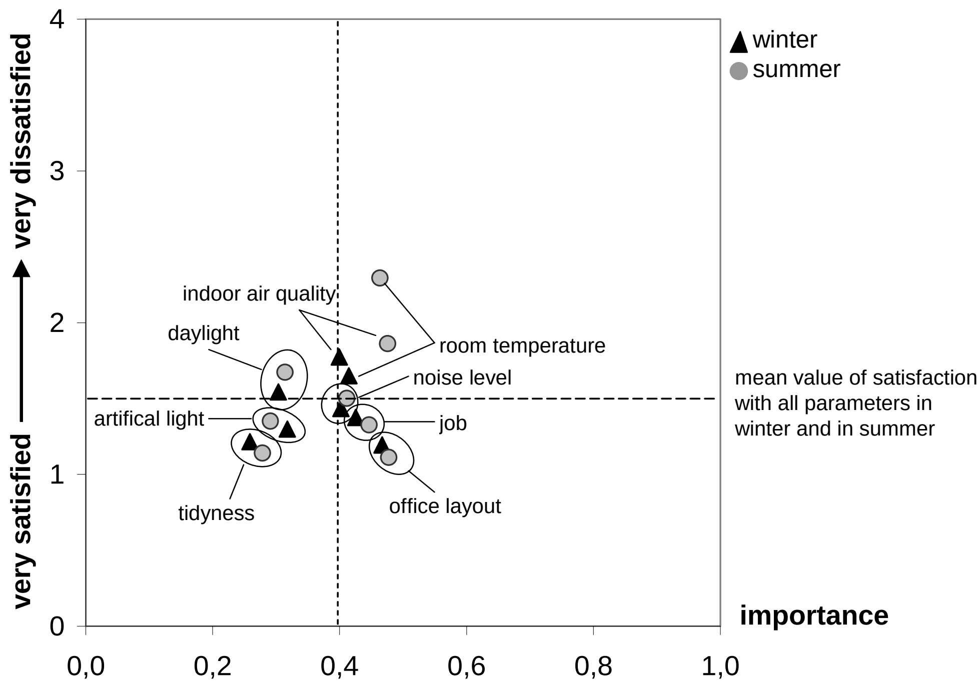

Figure 7: Matrix with all relevant satisfaction parameters for all investigated buildings. The parameters are weighted by their correlation coefficients against the overall satisfaction with the workplace

A matrix like this can be derived for every single building on the basis of a survey and provides a straight-forward assessment of building performance by showing the optimisation potential for each parameter. In combination with the mean values of the satisfaction parameters, the need for changes in the building and the possibility to raise the occupants' satisfaction and productivity becomes transparent to the building manager. This includes not only the operation of technical systems but also the possibility to assist the occupants in "operating their workplace" according to the specific building and indoor climate concept. The surveys confirmed that the parameters with the highest optimisation potential were also addressed by the occupants as those which predominantly affected their self-estimated productivity.

Conclusions

By applying multivariate analysis to survey data of a field study in 17 buildings, correlations between different parameters with regard to satisfaction at workplaces could be found and validated. The surveys were carried out in office buildings twice a year in order to find seasonal differences mostly in the votes on thermal comfort and lighting.

The most distinct interrelations between relevant parameters could be found for the field of thermal comfort. It became obvious, that the thermal sensation is not the strongest factor which influences the satisfaction at workplaces if real working environments are examined. Here, the perceived effectiveness of attempted temperature changes is dominant.

Votes on thermal perception showed significant differences between winter and summer for comparable indoor temperatures. In correspondence, the dissatisfaction with the indoor temperature for a neutral thermal perception was higher in summer. Although most of the investigated buildings had indoor temperatures which lay within the comfort range of DIN EN ISO 7730 only 30% of the occupants were very satisfied or satisfied with the temperature at their workplace. Other comfort parameters did not show considerable differences between winter and summer in the different buildings.

Work-related factors like stress or responsibility were named by the occupants in a comparable intensity as in other studies, e.g. [10], but did not have a considerable influence on the well-being or the satisfaction parameters as it could be shown for the indoor climate and daylighting. On the other hand indoor climate and daylighting correlated with the occupants' statements on perceived health at their workplace.

Based on statistical analysis a routine was introduced which enables to assess building performance by POE. By weighting single satisfaction parameters a matrix can be generated which shows the potential of these parameters in terms of performance optimisation and the necessity to act for the building manager. By including the occupants into this optimisation process their satisfaction can be further increased because of a higher transparency of the building management.

The results and findings of this study are mostly in good accordance with other international studies or provide complements to them. A detailed review of similar studies, their outcome and the context to this study is given in [11].

References:

[1] www.enob.info

[2] Leaman, A.; Bordass, B. (2001): Assessing building performance in use 4: the probe occupant surveys and their implications, Building Research and Information, vol. 29(2), pp. 129-143

[3] Schneider, W.; Windel, A.; Zwingmann, B. (2003): Die Zukunft der Büroarbeit, Initiative neue Qualität der Arbeit (INQA-Studie)

[4] Roulet, C. A.; Flourentzou, F.; Foradini, F.; Bluyssen, Ph. ; Cox, Ch.; Aizlewood, C. (2006): Multi-criteria Analysis of Health, Comfort and Energy Efficiency of Buildings, Building Research & Information, vol. 34(5), 475-482

[5] Nicol, F.; Mc Cartney, K. (2000): Smart Controls and Thermal Comfort Project (SCATs), final report

[6] Gossauer, E. (2008): Nutzerzufriedenheit in Bürogebäuden - eine Feldstudie. Dissertation an der Universität Karlsruhe.

[7] van der Linden, A.C.; Boerstra, A. (2006): Adaptive temperature limits: A new guideline in the Netherlands. A new approach for the assessment of building performance with respect to thermal indoor climate, Energy and Buildings, vol. 38, 8-17

[8] Fahrenberg, J. et al. (2002): Evaluation des negativen Retrospektionseffektes. Untersuchungen mit MONITOR, Universität Freiburg, Forschungsbericht des Instituts für Psychologie, Nr. 156

[9] Hellwig, R.T. (2005): Thermische Behaglichkeit – Unterschiede zwischen frei und mechanisch belüfteten Gebäuden aus Nutzersicht, Dissertation an der Universität München

[10] Richter, G. (2000): Psychische Belastung und Beanspruchung – Stress, Psychi-sche Ermüdung, Monotonie, psychische Sättigung, Wirtschaftsverlag, Bremerhaven

[11] E. Gossauer, A. Wagner (2006): Post Occupancy Evaluation and Thermal Comfort - State-of-the-Art and new Approaches. Annual Journal of Advanced Building Energy Research, Vol. 1, December 2006