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Correlation between temperature satisfaction and unsolicited complaint rates in commercial buildings

Abstract This paper analyzes the relation between temperature satisfaction ratings expressed on a questionnaire and unsolicited complaint rates recorded in a maintenance database. The key findings are as follows: (i) the satisfaction ratings and complaint rates are negatively correlated with a moderate magnitude ($r_s = -0.31$ to -0.36), and the correlation is statistically significant ($P = 0.01$–0.005), and (ii) the percent dissatisfied with temperature and the complaint rate are positively correlated with moderate magnitude ($r_s = 0.31$–0.36), and the correlation is statistically significant ($P = 0.01$–0.004). Both data sets contain 'real-world' measures of temperature satisfaction, with the complaints contributing directly to the cost of operations and maintenance. The relationship between two validates a new method of assessing the economic cost of thermal discomfort in commercial buildings.

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Key words: Thermal comfort; Satisfaction; Complaints; Correlation; Economic cost; Commercial buildings.

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Practical Implications

Complaints in commercial buildings indicate occupants' dissatisfaction to their environments. It not only deteriorates occupants' performance and organization productivity, but also increases building maintenance and operating cost. Nailing economic consequences of complaints will enable monetary comparison of discomfort cost with building and operating costs. This comparison may be desirable for building owners and tenants to make well-informed decisions on construction, rental, and retrofit. It may also be used to evaluate complaint diagnostic and eliminating techniques.

Introduction

In commercial buildings, when occupants become too hot or cold and have exhausted all coping behaviors, they sometimes complain to the facility manager. A technician is typically dispatched to the complaint location to investigate the cause and resolve the problem. Sometimes the technician must adjust the air-conditioning systems to meet the occupants' requirements. According to Federspiel (1998, 2001), 'too hot' and 'too cold' are the overwhelming majority of unsolicited complaints (77%) in buildings. Hot or cold complaints are rarely due to inter-individual differences in preferred temperature. They are usually due to HVAC faults or poor control performance. Most actions taken in response to thermal complaints involve adjusting control system set points or changing the status of equipment.

At a minimum, the cost of an individual complaint is equal to the labor cost of the technician. It is estimated that the labor costs alone amount to millions of dollars annually in the US. It is likely that there are other costs associated with complaints such as productivity loss. According to Fisk and Rosefeld (1997), productivity loss due to thermal conditions is $12–125 billion annually in the US. Thus, reducing the frequency of hot and cold complaints has a significant economical influence on reducing the labor cost and improving worker productivity.

Thermal comfort research has been one of the major efforts of HVAC engineers since the early twentieth century. It has been widely accepted that there are multiple factors that influence an occupant's thermal sensation, including air temperature, humidity, air velocity, mean radiant temperature, and individual factors such as metabolic rate and clothing level

(ANSI/ASHRAE Standard 55–92, 1992). Based on heat balance analysis and other additional assumptions, Fanger (1967) formulated the comfort equation. Later, Fanger (1972) related the heat load to data from various laboratory studies and obtained the Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied indexes, which are now widely used to predict the comfort of average sedentary person.

Thermal comfort and the levels of satisfaction of an individual toward the thermal environments have been surveyed in numerous field studies since the 1970s. Such surveys usually ask respondents to vote their instantaneous thermal sensations on a 7-point scale (the same scale as PMV) and their satisfaction level (or acceptability level) in a similar categorical scale. It is now common practice for large organizations, particularly facility service organizations, to ask questions similar to these with questionnaires.

The existence of large sets of survey data, combined with large computer-based maintenance databases now makes it possible to associate economic cost with dissatisfaction expressed on surveys. This is possible because unsolicited complaints can be directly related on the cost of operation and maintenance. To our knowledge, the only relationship between satisfaction or thermal sensation levels and complaints is that deduced by Federspiel (2000), which demonstrated that temperature level at which occupants complain is equal to ± 2.5 scale units on a bipolar, 7-point scale. There is no information on the relationship between temperature satisfaction and complaint rates.

This paper describes an empirical analysis of the relationship between temperature satisfaction ratings expressed on a questionnaire administered to assess the quality of facility services (i.e. not for research purposes) and complaint rates recorded in a maintenance database. Both data sets contain 'real-world' measures of temperature satisfaction, with the complaint data being directly attributable to the cost of operations and maintenance. The relationship between these two variables validates a new method of assessing the economic implications of dissatisfied building occupants.

Hypothesis

A partial causal relationship may exist when one states that if occupants complain, they must be dissatisfied. However, a dissatisfaction rating on a survey does not necessarily imply that the occupant complains frequently. There may be factors that cause a dissatisfied occupant to decide not to make complaint calls although he is not thermally satisfied. Nevertheless, we would expect that dissatisfied occupants would be more likely to complain than satisfied occupants. We thus hypothesize that satisfaction rating and complaint rate are statistically correlated, and that the correlation between the two is negative.

Two pairs of hypotheses are tested.

1. *The null hypothesis*: Complaint rate is independent of satisfaction rating. *The alternative hypothesis*: Complaint rate is negatively correlated with satisfaction rating.
2. *The null hypothesis*: Complaint rate is independent of percent dissatisfied. *The alternative hypothesis*: Complaint rate is positively correlated with percent dissatisfied.

Those two hypotheses are different but not independent. When the complaint rate is interpreted as the likelihood of an average person to complain, its association with the satisfaction rating would be useful. When the complaint rate is taken as a population characteristic for a building, the survey participants are random samples from the population, so the later hypothesis would be useful. This hypothesis may result a more significant result than the first one if we hypothesize that the complainers are those who are dissatisfied. It may also be more robust because the usage of survey scales may vary individually, but people seldom confuse dissatisfaction with satisfaction. However, in this study, data were not available to associate individual dissatisfaction with individual complaints.

Method of study

Survey instrument

Quality of facility services is usually surveyed on an annual basis. A proportion of occupants are randomly chosen to rate their satisfaction with a range of factors including building temperatures. As shown in Figure 1, occupant satisfactions with winter and summer temperatures are asked using a standard 5-point scale.

Complaints record

In the buildings in this study, hot and cold complaints are recorded in a modern computerized maintenance management system (CMMS). Complaints are initiated by occupants as unsolicited phone calls to a

	1 Very dissatisfied ▼	2 ▼	3 ▼	4 ▼	5 Very satisfied ▼	Cannot Rate ▼
Temperature. Summer ……..	□	□	□	□	□	□
Temperature. Winter ……….	□	□	□	□	□	□

Fig. 1 Survey temperature question

maintenance call center. The call center records the pertinent data (including time and location) in the CMMS, then dispatches the call to the appropriate maintenance personnel. We used the time, location, and complaint type data to match hot/cold complaint data to survey data.

Data preparation

Occupants' satisfaction usually is surveyed anonymously in each building. Complaints are generally random in time and location. Because of these factors we were not able to check correlation between satisfaction and complaint rate at the individual level. Instead, we investigate the correlation at the building level.

We collected 2001–2002 survey results in 184 buildings. In the same time period, complete complaints records were available from 51 buildings in 2001 and from 55 buildings in 2002. The buildings with <25 occupants or <5 survey participants were removed from the analysis. These constraints resulted in field data from 45 buildings. The complaints were clustered in two seasons (12/22–3/22 for winter 6/22–9/22 for summer). The complaint rate in the analysis was normalized by plan area of the building (complaints/m^2/one season), or by the occupancy of the building (complaints/person/one season) to remove the confounding influences of building size or occupant density. The satisfaction rating in the analysis was the average rating on the 5-point scale, or the percent dissatisfied (assuming 1 and 2 on the scale represent dissatisfaction).

Statistical analysis

We used a rank-based nonparametric method to test the association of interest. Nonparametric methods have advantages over parametric methods in terms of minimal assumptions about the observations. There is no normal distribution requirement for the complaint rate and satisfaction rating. The rank-based methods do not require the pre-assumption of linear or nonlinear association. The disadvantage of non-parametric methods is that they are less efficient.

Two commonly used rank-based nonparametric statistics are Spearman's rank correlation coefficient and Kendall correlation coefficient.

Spearman's rank correlation coefficient r_s is calculated as:

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum x^2 \sum y^2}}, \quad (1)$$

where x and y are two ordinal variables, with $d_i = x_i - y_i$.

$$\sum x^2 = \frac{N^3 - N - T_x}{12}, \quad (2)$$

where N is sample size, and $T_x = \sum_{i=1}^{g}(t_i^3 - t_i)$ is used to deal with tied ranks, g is the number of groupings of different tied ranks, t_i is the number of tied ranks in the ith grouping. Similar adjustment is applied to y. The power efficiency ratio of Spearman's correlation coefficient with respect to Pearson's product-moment correlation is 0.91 (Siegel and Castellan, 1988).

For two ordinal variables, the probability of the occurrence of any particular r_s is proportional to the number of permutations giving that value. If two variables are independent, r_s will be different from zero only by chance. The critical r_s has to be computed by counting all the possible permutations. The results in this paper were produced using the correlation functions in a commercially available computer-based statistics application.

Kendall's τ uses the same ordinal information as in Spearman's CC but it has a different interpretation. It is the difference in probability that, in the observational data, x_i and y are in the same order and the probability when x_i and y_i are in the different order. It goes in the range −1 to 1. Kendall's τ and Spearman's CC are not directly comparable. But they have the same power for testing this association. The detailed procedure to compute τ can be found in (Siegel and Castellan, 1988).

Results

Complaint rate is correlated with the mean satisfaction rating, and the correlation is significantly negative. Complaint rate is correlated with the percent dissatisfied, and the correlation is significantly positive. The results of the hypotheses test are summarized in the Tables 1 and 2.

Table 1 Test result for complaint rate and satisfaction rating

	Spearman's CC			Kendall's τ		
Testing pairs	r_s	*P*-value (two-sided)	*P*-value (negative)	τ	*P*-value (two-sided)	*P*-value (negative)
Complaints/m^2/season and satisfaction rating	−0.3633	0.0102	0.0051	−0.2360	0.0145	0.0072
Complaints/person/season and satisfaction rating	−0.3128	0.038	0.019	−0.2111	0.0408	0.0204

Table 2 Test result for complaint rate and percent dissatisfied

	Spearman's CC			Kendall's τ		
Testing pairs	r_s	*P*-value (two-sided)	*P*-value (positive)	τ	*P*-value (two-sided)	*P*-value (positive)
Complaints/m^2/season and percent dissatisfied	0.3663	0.0096v	0.0048	0.2313	0.0165	0.0083
Complaints/person/season and percent dissatisfied	0.3182	0.029	0.0146	0.1986	0.0464	0.0232

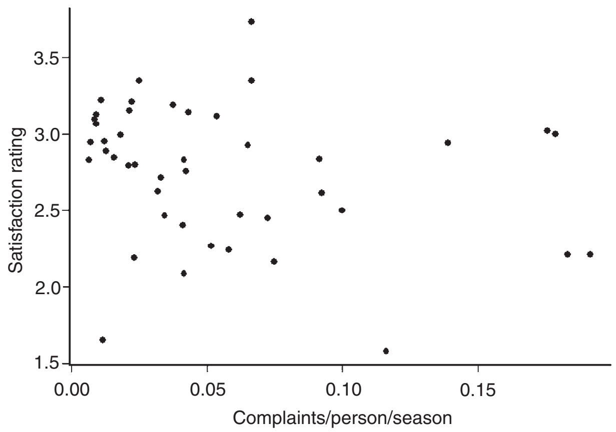

Fig. 2 Negative correlation between complaint rate and satisfaction rating

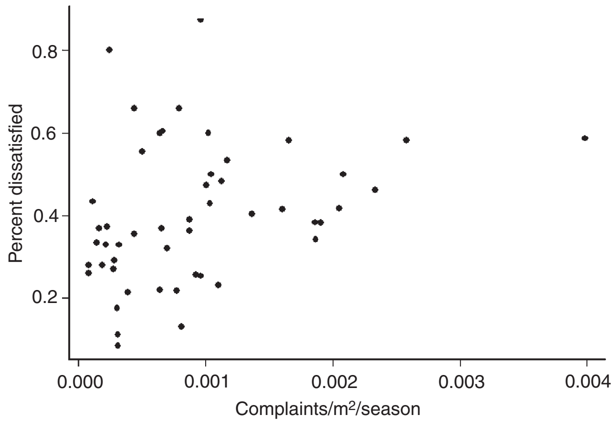

Fig. 3 Positive correlation between complaint rate and percent dissatisfied

Figure 2 displays the mean satisfaction rating versus the complaint rate. Figure 3 displays the percent of dissatisfied versus the complaint rate. The magnitude of the correlation is moderate in both cases.

The mean satisfaction rating in summer is highly correlated with the mean satisfaction rating in winter; they are linearly related with a slope of one. The complaint rates in summer are also correlated with the complaint rates in winter, but the correlation is lower than for mean satisfaction ratings. These findings are displayed in Figure 4 for 2001 data. These findings suggest that we may increase the sample size or decrease the noise by combining winter and summer satisfaction ratings.

Figure 5 shows a better display of the negative correlation between complaint rate and satisfaction rating when satisfaction rating is computed by averaging winter and summer satisfaction ratings, and complaint rate is computed by summing winter and summer complaints.

Table 3 shows the recalculated correlations after averaging winter and summer satisfaction and adding winter and summer complaints. Correlations are stronger than before, in moderate to strong magnitude.

Discussion

The correlation between the complaint rate and the percent dissatisfied is moderately positive. This implies that a building with more complaints will tend to have higher dissatisfaction ratio. Conversely, a building with higher dissatisfaction ratings will tend to have more complaints, and potentially have higher maintenance cost. All things being equal, a building with more dissatisfied occupants will tend to cost more to operate.

It will be very useful if we could find a predictable relationship between the percent dissatisfied and complaint rate. However, given relatively low r_s and τ values, the prediction of one from another would be unreliable. One explanation is the small sample size this study used. The current result comes from 45 buildings in a single geographical area of the US. This relatively small sample size and single location may restrict us from obtaining a stronger statistical relationship. As we increase the sample size and reduce noise by averaging winter and summer satisfaction ratings and adding winter and summer complaints, a stronger correlation is found. If we were able to collect larger amount of data, or to extend this study to buildings in wider geographic regions, the quantitative prediction would be more informative.

In an earlier study (Federspiel, 2000), the complaint temperatures were recorded. The likelihood of a complaint was modeled as a function of the statistical properties of the indoor temperature process. It is possible that if we have temperature as a third variable measured in addition to the complaints and satisfaction rating, a refined prediction model could be developed.

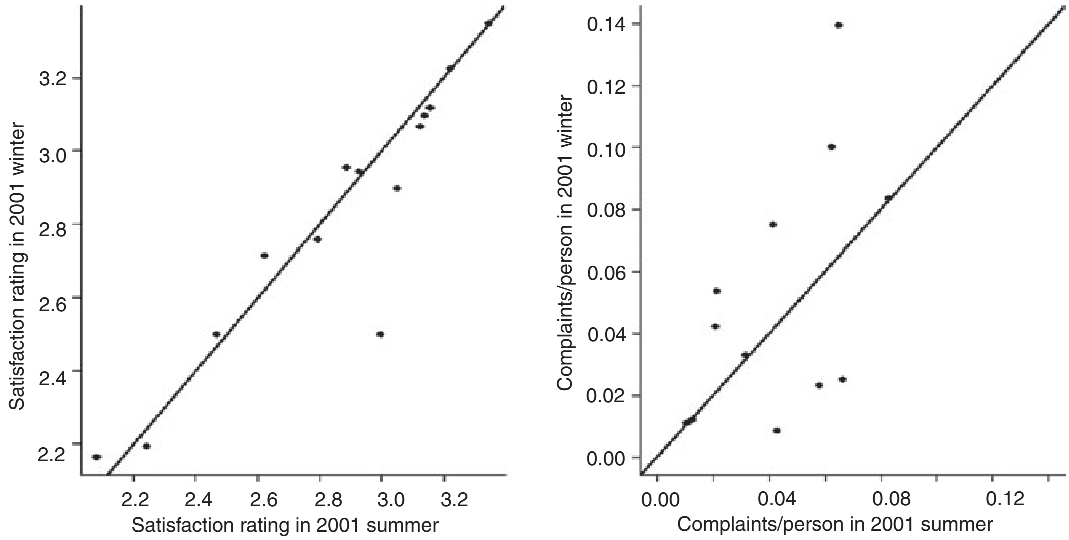

Fig. 4 Linear correlation between winter and summer data for both satisfaction and complaints

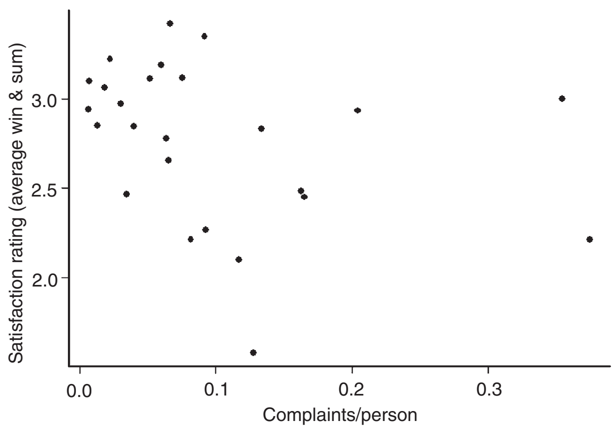

Fig. 5 Negative correlation between complaint rate and satisfaction rating when winter and summer ratings are combined

The correlation between the complaint rate and the satisfaction rating is moderately negative. The explanation is that occupants feel uncomfortable, so they complain and say they are dissatisfied. In other words, discomfort causes complaints and dissatisfaction. However, it may be that occupants rated their satisfaction low because they remembered having to register complaints, or that complainers are those who are dissatisfied with the temperature. It is worth noting that even if two variables are highly correlated, it is not a sufficient proof of causation in either direction. This difference has been highlighted in many social/behavioral studies, for example, the correlation between cigarette smoking and lung cancer (Pearl, 2001).

When the satisfaction rating in summer is compared with that in winter, the relationship is linear with the slope of one. At first thought, this might imply that asking two questions about temperature (summer and winter) adds no information. Occupants may be casually giving similar responses to the questions in winter and summer. However, there is a linear relationship between the complaint rate in summer and the complaint rate in winter, with the slope being close to one. This finding suggests that the information about summer vs. winter satisfaction may be accurate.

Conclusion

From analysis of the field data in 45 commercial buildings, we find that:

1. The satisfaction ratings and complaint rates are negatively correlated with a moderate magnitude ($r_s = -0.31$ to -0.36), and the correlation is statistically significant ($P = 0.01$–0.005). The recalculated correlations after averaging winter and summer satisfaction and adding winter and summer complaints shows stronger correlation between two $r_s = -0.42$ to -0.54), and ($P = 0.01$–0.003).

Table 3 Improved test result for complaint rate and satisfaction rating

	Spearman's CC			Kendall's τ		
Testing pairs	r_s	*P*-value (two-sided)	*P*-value (negative)	τ	*P*-value (two-sided)	*P*-value (negative)
Complaints/m^2 and satisfaction rating	−0.5421	0.006	0.003	−0.3675	0.007	0.004
Complaints/person and satisfaction rating	−0.4223	0.038	0.019	−0.2667	0.0617	0.0309

2. The percent dissatisfied with temperature and the complaint rate are positively correlated with moderate magnitude ($r_s = 0.31–0.36$), and the correlation is statistically significant ($P = 0.01–0.004$).
3. Given relatively low correlation values, the prediction of complaints rates from satisfaction ratings, or vice versa, is not reached in this study. However, the intended relationship may be established if larger data set were available.

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