#4018

ASHRAE STANDARDS: A GUARANTEE OF OCCUPANT SATISFACTION?

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ABSTRACT

As a result of occupant complaints, an extensive environmental analysis was conducted on a large new government office building in 1980. Recommendations were made to improve performance of the ventilation systems as well as to restructure the open office layouts so that the illumination and mechanical system capabilities would not be defeated. These recommendations were implemented on two floors as a trial. Environmental tests were again conducted in 1984/85 prior to implementing the recommendations in the rest of the building. In addition, a questionnaire was administered to more than 600 employees on the test floors.

With minor exceptions, it was found that ASHRAE ventilation air quality, thermal comfort, acoustic requirements, and IES illumination requirements were met. About 50% of the employees, however, rated their acoustical privacy, ventilation and air circulation very poorly, much worse than other environmental and job-related parameters. The surprising air quality results raise several fundamental questions concerning standards and their application.

THE PROBLEM

As a result of occupant dissatisfaction, an environmental performance study was conducted in a major Canadian government office building in the winter of 1980 and spring of 1981. Factors studied included (1) outdoor air ventilation rates, (2) air distribution, (3) air circulation patterns, (4) indoor air pollution levels, (5) thermal comfort parameters, (6) illumination, (7) acoustics, (8) vibration, and (9) ionizing and nonionizing radiation.

The results of these tests indicated many areas where the ventilation and illumination systems were not delivering as good a level of performance to the building occupants as was originally intended. This led to the issuance of a series of recommendations and guidelines. Some of these concerned adjustment or tuning of the mechanical and thermal control systems; others concerned changes to the interior and involved furniture and open office privacy screens.

Recommended systems adjustments included (1) rebalancing the air handling systems, (2) adding diffusers, (3) moving and adding thermostats, (4) relocating and modifying air return ducts, and (5) adding luminaires in areas where junctions in ceiling systems prevented the installation of standard ceiling lighting modules.

Recommended means of improving workstation layouts and making more effective use of open office screens included (1) relocating some workstations very close to the building perimeter, (2) raising open office screens off the floor, (3) using fewer open office screens, (4) making the screens higher in reflectance, (5) making the screens lower in height, and (6) orienting the screens with respect to local air currents, in some cases.

Recommendations concerning workstation layouts were based on the following observations:

1. The lighting systems performed very well in totally open office environments. The luminaires cast much of their light to the sides. Unfortunately, in most of the building, where large numbers of tall, dark open office screens were used, much of

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the lighting was cut off before it reached the workstation and was not reflected. The result was that the quality and quantity of illumination decreased dramatically.
2. The air diffuser system delivered excellent performance in totally open areas, creating a very subtle circular air flow pattern that penetrated almost to the floor. Where there were large numbers of high, open office screens that went to the floor, the air was observed to circulate over the top of the screens only. At some workstations, tracer gas tests illustrated a time delay of up to 20 minutes between building fan energization and introduction of ventilation air to the workstation at sitting nose level.
3. In spite of excellent open office sound absorption properties, acoustic privacy could not consistently be attained between open office workstations. This was partially due to space limitations (15 m^2 or 150 ft^2 per person including common areas such as boardrooms, circulation space, etc.) but was also due to the low ambient noise levels (often as low as NC 30).

In total, these factors created a situation where, even if the building systems were made to operate in a fully satisfactory manner, unsatisfactory conditions in the workspace would often result because the space was used. This situation existed in spite of, or perhaps because of, conscientious efforts to deliver an environment with excellent illumination, ventilation and acoustical properties.

THE SEARCH FOR A SOLUTION

Two different styles of trial interior layouts were constructed in 1983 on the second and third floors of the building in response to changes in internal organization. Attempts were made in both cases to incorporate the previous recommendations. The Building Performance Division was asked late in 1984 to evaluate the environmental performance of these two floors in order to find which design solution worked best. The intent was that successful modifications would be incorporated in other building layout plans as changes became necessary. The results of that second study form the basis of this paper. The second study was very similar to the first except that a questionnaire was also issued to a stratified random sample of approximately 300 occupants on each of the two floors tested.

SECOND STUDY FINDINGS

Acoustics

The acoustical performance on both floors was very similar. Ambient noise levels ranged from NC 31 to 38. Open office voice attenuation remained excellent, approximately 5 to 6 dB/doubling of distance. In spite of this, acoustical privacy between adjoining workstations remained poor. Articulation indices (AI) based on measured values between nearest workstations ranged from 0.2 to 0.4. Analysis of results showed that the easiest way to increase acoustical privacy was by increasing the ambient noise level. Even then, consistently good acoustical privacy between adjacent workstations as defined by an AI of less than 0.15 still could not be attained within existing space limitations if the ambient noise level were to remain reasonable (i.e., less than NC 45) and open office construction was to continue to be used.

Illumination

The general quality of illumination had been significantly improved where fewer, lower, and/or more reflective open office screens had been used. Isolated problem areas still remained on the two test floors near columns and on one of the floors at the intersection of ceiling grid patterns. In the vast majority of work areas, sufficient quantity of illumination was supplied at the workstation to meet Public Works Canada and IES illumination requirements.

Ventilation and Air Quality

The mechanical system in this building is a constant volume, dual-duct system with an economizer cycle. It does not go to minimum fresh air rates until the outside air temperature drops below approximately 10°C (14 F) or until it exceeds approximately 22°C (72 F).

A large amount of outdoor air enters the building during most of the year; it is well mixed and is well distributed (small offices and boardrooms excepted). Measured and calculated ventilation rates are presented in Table 1. As illustrated by Table 2, at the time of measurement, the building interior air contained low existing quantities of pollutants compared to existing standards.

Smoke pencil tests conducted during this second set of tests showed ventilation air now to be penetrating into workstations. CO_2 test results did not reveal any obvious pockets of buildup, although it may have been difficult to identify "potential problem" areas due to the low overall CO_2 levels listed in Table 2.

Thermal Comfort

Ambient indoor air temperature was measured and ranged between 22°C (72 F) and 25°C (77 F) with the majority of workstations having ambient temperatures of less than 24°C (75 F).

Temperatures generally varied by less than 0.5°C (1 F) during the working day. Relative humidity was controlled at 22% to 30% RH, varying with workstation air temperature. Although this set of measurements does not address all of the factors contained in the ASHRAE thermal comfort standard, the results are not unreasonable.

OCCUPANT PERCEPTIONS (QUESTIONNAIRE RESULTS)

The results of a questionnaire issued to the two test floors showed that the worker profile was similar for both floors, except that there were more:

1. women clerical workers and long-term employees on the third floor,
2. employees who worked overtime on the second floor,
3. video display terminals on the second floor, and
4. fans and heaters on the third floor.

In both cases, approximately 36% of employees were smokers. The existence of similar groups of occupants on each floor is important since it means that differences in occupant judgments of the work environment on each floor would be more easily attributed to environmental differences rather than to social or work-group characteristics.

FLOOR-TO-FLOOR DIFFERENCES IN PERCEIVED PERFORMANCE

Initial questionnaire results indicated a large difference in performance between the two test floors. The sex bias in population distribution was then factored out by comparing women's responses to women's responses and men's to men's. With some minor and explicable exceptions (i.e., window accessibility) all the environmental performances differences then disappeared. The results that follow are the total of the raw results for the two test floors with no attempt to adjust for male to female ratios or other possible biases.

Perceived Performance

The occupants' ratings of the building's performance are presented in Tables 3 to 7. Generally, one indicates poor performance and five indicates excellent performance.

Background ratings (Table 3) indicate how the occupants felt about the building, the maintenance, their workspace, and their job as a whole. These provide good reference points for judging other environmental performance ratings.

Acoustics and privacy ratings (Table 4) indicate how the occupants felt about their open office acoustics. There are no surprises here, except, perhaps, the strength with which they expressed dislike of their obvious lack of open office acoustical privacy.

Illumination performance ratings (Table 5) indicate how the occupants felt about their illumination. Again, there are few surprises here. PWC standards are based upon IES guidelines. They are not intended to please more than 80% of the occupants.

Thermal performance ratings (Table 6) also do not appear to be unreasonable. The building was controlled near the upper end (and sometimes exceeded) the range of permissible temperatures suggested by ASHRAE. In spite of this, 80% of the building occupants did not strongly express thermal discomfort.

The air quality and ventilation ratings (Table 7) are very interesting. "Only" 19% of those surveyed rated odor control poorly. This is consistent with the known fact that the building is well ventilated. These facts do not appear to be consistent, however, with the surprisingly large proportion (approximately 50%) of the population that rated air freshness and air movement poorly. The "good" rating of odor control may be explained by olfactory adaptation of the occupants to their environment. This does explaining, however, the discrepancy between fresh air rates and ratings of ventilation and air freshness nor is it certain that these factors are necessarily related (i.e. an odorless irritant).

Discussion

ASHRAE's current guidelines for ventilation and air quality are intended to please about 80% of the people in an environment. The thermal comfort and illumination guidelines to which the building largely conforms were similarly developed. It is interesting to note that, although the questionnaire data developed here are not directly comparable to these standards, close relationships seem to exist in many cases. "Only" 16% to 20% of the questionnaire respondents rated their thermal environment, illumination environment, and odor control as "worst." This must be sharply contrasted to ventilation, air freshness, and air movement, where 39%, 50%, and 47% of the occupants rated each of these issues as "worst." Clearly, perceived odor control and fresh air rates were not the only factors having an impact on the acceptability of ventilation to the building's occupants. Several fundamental questions must be raised.

1. Are the performance measurement tools inaccurate? Perhaps the questionnaire used was biased. This is possible, but the biases would have to be extremely large to change the trends measured here. Nevertheless, the questionnaire and data analysis techniques used by Building Performance are currently being closely scrutinized. Perhaps the physical performance measurements were wrong. This also seems unlikely due to good correlation between different sources of data (i.e., CO_2 levels versus ventilation rates or our balancing checks versus the most recent balancing report).

2. Can we afford to dissatisfy 20% of the building's population with each environmental criteria? Most of our standards individually aim to please only 80% of the population. One need only consider the potential compounded effect of randomly distributed occupant dissatisfaction resulting from barely meeting the requirements of three different environmental performance standards. Almost 50% of the population would be legitimately and predictably dissatisfied with some aspect of the building's performance even though all stipulated performance requirements had been met.

   One must also examine how these environmental attributes combine. As an example, it is well accepted by property managers that warm conditions will increase air quality complaints. Let us assume we have a situation where at the mid-point of the ASHRAE thermal comfort range, 80% of the building's occupants are not dissatisfied with air quality. If ambient air temperatures then rise to near the upper limit of the thermal comfort standard, it seems reasonable to suppose that some percentage less then 80% of the building's population may remain satisfied with the building's air quality.

3. Are the standards based upon the right criteria? In spite of apparently reasonable odor control, 50% of the people rated their air freshness as "worst." It is possible that other factors such as long term eye, nose and throat irritation due to second-hand tobacco smoke or other pollutant sources, can be at least as important as odor control.

   About 50% of the people were also unhappy with the air movement. It is very possible, in this case, that the perception of poor air quality is not a result of a lack of outside air but is due to a lack of perceived air motion. It is very possible that we need performance-based standards for important criteria such as a local air circulation patterns, which will affect either ventilation effectiveness or the perception of ventilation air currents.

4. Were occupant expectations unreasonable? Is so, then obviously they cannot reasonably be met. Sensitization of these building occupants to this issue by reports of poor air quality in nearby government complexes cannot be lightly dismissed.

Recommendation

The resolution of these questions is very important. Currently, these standards are applied with the expectation that they will ensure the provision of a reasonable quality of environment without requiring unreasonable expenditures. If this is not the case, then clearly, our reliance on these standards must be tempered.

CONCLUSIONS

1. With a few isolated exceptions, the building meets existing performance standards.
2. The building occupants were not entirely happy with the building's performance. They were especially dissatisfied with air quality and with acoustical performance.
3. Meeting current air quality and ventilation standards has not ensured a reasonable level of occupant satisfaction.
4. If physical performance standards are to be used as a means of ensuring a minimum level of occupant satisfaction, then these standards must be carefully re-examined. In particular, it must be ensured that the level of satisfaction the individual standards tend to create is appropriate, that they address all necessary factors, and that they interrelate, or at least, do not conflict.

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TABLE 1
Ventilation Performance

Total Air	3.0 - 3.9 l/s*m2
Outside Air	15 - 100% (estimated of total ventilation air)
	10 - 75 l/s* person (calculated)
Relative Humidity	22 - 28%
Temperature Control	22 - 25oC
Balancing:	
Perimeter Diffuser Velocities	Goal: 3.5 m/s
	Measured: 3.25 - 3.75 m/s
Interior Diffuser Velocities	Goal: 1.5 m/s
	Measured: 1.25 - 1.75 m/s

TABLE 2
Indoor Air Quality

POLLUTANT	CONCENTRATION MEASURED
Carbon Dioxide	440 - 610 ppm
	770 ppm (worst case closed office)
	330 ppm (outdoor air)
Carbon Monoxide	2.5 - 5 ppm
Total Suspended Particulates	<0.2 mg/m3 (lower detection limit)
	0.3 mg/m3 at 1 measurement point
Formaldehyde	<.02 ppm (lower detection limit)
	.06 ppm at 1 measurement point

Note: The outdoor ventilation rate was approximately 25 L/s person at the time of measurement.

TABLE 3
Selected Background Ratings

ISSUE:		RATING: 1	2	3	4	5	
Overall Building	(worst)	22	29	37	11	2	(best)
Maintenance	(worst)	7	26	44	21	2	(best)
Workspace Layout	(worst)	17	27	39	16	2	(best)
Workspace Separation	(worst)	10	27	35	24	4	(best)
Amount of Space	(worst)	11	20	28	31	10	(best)
Screen Arrangement	(worst)	16	23	29	28	4	(best)
Colour in Workspace	(worst)	42	32	21	5	1	(best)
Window Accessibility	(worst)	39	26	20	11	5	(best)
Lounge Availability	(worst)	35	22	24	15	4	(best)
Circulation in Workspace	(worst)	14	26	38	18	4	(best)
Job Satisfaction	(worst)	1	6	34	44	16	(best)

TABLE 4
Acoustics and Privacy Ratings

ISSUE:		RATING: 1	2	3	4	5	
Noise Distractions	(worst)	31	32	27	9	2	(best)
General Noise Level	(too noisy)	28	37	33	9	5	(comfortable)
Air System Noise	(disturbing)	5	14	21	21	39	(not a problem)
Oral Communication	(hard to hear)	10	15	30	20	25	(clearly audible)
Voice Privacy	(worst)	50	29	12	6	4	(best)
Telephone Privacy	(worst)	50	25	14	7	4	(best)
Visual Privacy	(worst)	32	29	19	17	4	(best)

TABLE 5
Illumination Performance Ratings

ISSUE:		RATING: 1	2	3	4	5	
Electrical Lighting	(worst)	16	21	34	25	4	(best)
Brightness	(too bright)	10	13	34	18	25	(not too bright)
Darkness	(too dark)	6	14	31	17	31	(not too dark)
Lighting Glare	(high glare)	10	14	25	22	29	(no glare)

TABLE 6
Thermal Performance Ratings

ISSUE:		RATING: 1	2	3	4	5	
Temperature	(worst)	16	29	36	27	2	(best)
Cold	(too cold)	16	20	28	22	14	(comfortable)
Hot	(too warm)	20	23	29	19	10	(comfortable)

TABLE 7
Air Quality and Ventilation Ratings

ISSUE:		RATING: 1	2	3	4	5	
Ventilation	(worst)	39	29	22	8	2	(best)
Air Freshness	(stale)	50	25	18	6	1	(fresh)
Odours	(unpleasant)	19	15	27	16	24	(not noticeable)
Air Movement	(stuffy)	47	24	19	8	2	(circulating)