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Impact of psycho-social factors on perception of the indoor air environment studies in 12 office buildings

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Abstract

The main function of a mechanically ventilated office building is to provide a healthy and comfortable working environment for occupants, while maintaining minimum energy consumption. Twelve mechanically ventilated buildings were selected. They varied greatly in surface area, number of floors, occupant density, and building use. The indoor air quality, thermal comfort, energy consumption, and perception of occupants were investigated in these buildings. A total of 877 subjects participated in the questionnaire survey during the hot summer months of June, July, and August, and during the cold winter months of January, February, and March. The questions included in the questionnaire dealt with health, environmental sensitivity, work area satisfaction, personal control of the workstation's environment, and job satisfaction. Measured parameters concerning the quality of indoor air included ventilation rate, concentration of TVOC, CO_2, CO, RH, and formaldehyde. The thermal comfort parameters included room air, mean radiant, plane radiant asymmetry, and dew point temperatures, as well as air velocity and turbulence intensity. Monthly energy consumption data was also gathered for each building. Ventilation performance, in terms of air flow rate and indoor air quality, was compared with the ASHRAE Standard 62-89R (Ventilation for Acceptable Indoor Air Quality. Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. U.S.A. [1]). The measured and calculated thermal environmental results were also compared with the ASHRAE Standard 55-92 (Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. U.S.A. [2]). CO_2 and CO levels satisfied the recommended limits. The outdoor airflow rate was half that recommended in only one building. The formaldehyde and TVOC levels were moderately higher than suggested comfort levels. However, more than 56% of the occupants rated dissatisfaction with the indoor air quality. Only 63% of the indoor climatic observations fell within the ASHRAE Standard 55-92 summer comfort zone; 27% in the winter. However, only 69% of those surveyed agreed with the comfort zones. More symptoms were reported by workers who perceived IAQ to be poor. Positive relationships were observed between the job satisfaction and satisfaction with office air quality, ventilation, work area temperature, and ratings of work area environment. However, job dissatisfaction did not correlate with symptom reports. The occupants were more dissatisfied with IAQ when they preferred more air movement. In other words, the higher the perceived air movement, the greater the satisfaction with IAQ.

1. Introduction

The quality of indoor air has become a major concern ever since efforts to reduce ventilation rates in buildings started. It has long been recognized that the quality of indoor air should not be improved at the expense of higher energy consumption. However, good indoor air quality and energy conservation practices can be compatible. To achieve a good indoor environment at minimum cost, it is necessary to determine where IAQ, ventilation, and energy conservation are naturally in competition and where they can work together.

It has been found that meeting current air quality and ventilation standards does not ensure a reasonable level of occupant satisfaction [3]. A questionnaire was administered to more than 600 employees in a major Canadian office building during the winter months. The ASHRAE ventilation, air quality, thermal comfort, and acoustic requirements were generally met. Thermal performance ratings showed that the occupants were moderately satisfied, leaning towards discomfort due to temperatures that were too warm. The air quality and ventilation ratings showed that the occupants found the ventilation, the air freshness, and the air movement poor. The apparent dissatisfaction of the occupants compared with the apparent healthy and comfortable environment, questions the compounded effect of satisfying only 80% for each individual criteria, the criteria used to develop the

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standards, and the unreasonable expectations of the building occupants.

In an earlier study, Haghighat et al. [4] examined the relationships between the indoor environment parameters on two floors of an eleven-story building, as perceived by the occupants and as measured objectively. They showed that complaints reported by the occupants were associated with perceived rather than measured levels of indoor environmental parameters. The study was conducted over a 4-week period and consisted of measuring environmental parameters, and of administering a questionnaire on comfort and health, to 450 occupants. Most noteworthy in the responses was that more than 34% of the occupants expressed that the air was dry. The measured relative humidity ranged from 40–65%. More than 32% of the occupants expressed that in general, the thermal environment was unsatisfactory, even though almost all the measured thermal comfort parameters complied with the ASHRAE comfort standard. ASHRAE defines an acceptable thermal environment as "an environment that at least 80% of the occupants would find thermally acceptable" (ASHRAE Standard 55-1992).

The ANSI/ASHRAE Standard 55-92 'Thermal environmental conditions for human occupancy' (ASHRAE, 1992) is used extensively in Canada, as a reference for comfort levels. As more and more studies of Canadian buildings in the cold climate are emerging, it is apparent that the measured parameters satisfy the comfort limits as set out by ASHRAE, yet it is found that less than 80% of the occupants are satisfied [5]. ANSI/ASHRAE Standard 55-92 is based almost entirely on data from climate chamber studies performed in temperate climates. This perhaps explains the discrepancies between occupant satisfaction in a cold climate and satisfaction of workers in a temperate climate.

Building occupants often react to their environment in markedly different ways, and it is often difficult to identify the sources which are the cause of particular problems. The symptoms observed in building occupants are varied, and they depend greatly on the thermal parameters (air and wall surface temperatures, air velocity and fluctuation, relative humidity, clothing, etc.) contaminants (type and concentration), lighting, psychosocial factors (office space, personal control, job satisfaction, relation with co-worker, etc). The symptoms include headaches, dizziness, cough, eye irritation, unpleasant odours, fatigue, respiratory problems, and nose and throat irritation: these are the so-called symptoms of the 'Sick Building Syndrome' (SBS).

Therefore, symptoms of SBS are of multifactorial origin. It has been found that psychosocial work characteristics, such as workload and job satisfaction, as well as worry and reorganisation, are factors that have a significant impact on the risk of developing the symptoms of 'sick building syndrome' (SBS) [6, 7]. Skov et al. [8] and Eriksson et al. [6], found a strong relationship between 'satisfaction with superiors' and the prevalence of mucosal and general symptoms. Relations to supervisors was associated with a slightly increased risk. Skov et al. (1989) reported a strong association between 'satisfaction with colleagues' and symptoms. However, Eriksson et al. (1996) did not find such an association; nor did a feeling of poor work status have any impact on the risk of having symptoms. Eriksson et al. (1996) surveyed almost 6000 office workers from three cities in Sweden. They found that poor workplace satisfaction (salary, benefits, opportunities for growth, and personal development) was associated with a significantly higher risk (also supported by Zweers et al., [9]). However, Hedge [10] did not find any association between job satisfaction and SBS. Eriksson et al. [6] found that satisfaction with work seems to be irrelevant in this context, whereas satisfaction that refers to the workplace, i.e., rewards and opportunities for growth, appears to be a significant factor. They reported that an adverse psychosocial work environment may constitute a stress which causes symptoms through psychophysiological reactions. Thus, SBS may be regarded as a psychosomatic disorder, with psychological distress being expressed through physical symptoms. They also suggested that an adverse psychosocial environment may make the individual more attentive to discomfort and health, and to potential causes in the physical environment, and this could affect reporting behaviour. Another suggestion was that discomfort with the physical environment affects perception of the psychosocial environment. Or, a poor psychosocial environment may make the individual more susceptible to different adverse indoor climate factors.

The study reports the results of detailed measurements carried out during the heating and cooling seasons in twelve mechanically ventilated buildings, and examines the relationships between the indoor environment parameters as perceived by the occupants and as measured objectively, as well as the influence of psychosocial factors.

2. Building characteristics and measurements

Measurements were carried out at several workstations of 12 mechanically ventilated buildings. The measurements were performed during normal occupancy. The investigated buildings vary greatly in surface area (3000–68,000 m^2), in number of floors (2–25 storeys), in date of construction (1945–1992), in type of HVAC system (free cooling CAV, double duct VAV), and in type of tenant (police station, jail, court house, government offices, private company).

The measurements included physical and chemical monitoring, and assessment of the perceived indoor air quality and thermal comfort. The chemical measurements included concentration of TVOC, formaldehyde, CO_2, and CO. The physical measurements consisted in operative temperature, air temperature, relative humidity, air velocity and ventilation rate. A questionnaire for evaluating immediate symptoms was given to the occupants of the buildings. The questionnaire was divided into two parts: background and online. The background questions covered areas such as some demographics, health, environmental sensitivity, workstation, personal control of the workstation's environment, current clothing garments, and job satisfaction. The online questions were the traditional scales of thermal sensation and thermal preference, personal comfort, metabolic activity, and air movement acceptability. The monthly energy consumption of the building and the daily weather conditions were also recorded.

The records of outdoor weather conditions were obtained from the closest weather station to each building. The mean temperature and relative humidity for the summer season was 18 C and 74%, respectively. For the winter season, the mean temperature and relative humidity was −7 C and 72%, respectively.

The target sample size was 40 occupants (workstations) in each building. The occupants/workstations were chosen to represent 50% males and 50% females, 50% closed offices and 50% open-type offices, 50% in the centre of the building and 50% along the periphery. Two types of indoor climatic measurement systems were used: a mobile and a stationary system. The mobile system, CHARIOT, was wheeled into each subject's workstation. The stationary system was placed in a representative location within each building during the workstation visits, to record variations in the indoor climate.

The mobile system collected concurrent physical data: air temperature, dew-point temperature, vapour pressure, globe temperature, radiant asymmetry, air velocity, turbulence, air supply, air return, and room-temperature, illuminance, carbon monoxide, carbon dioxide, formaldehyde, volatile organic compounds, and tracer gas decay. The transducers and measurement points were placed to represent the immediate environment of the seated subjects.

The physical measurements were made at the exact physical position of the subject completing the subjective questionnaire, and as soon as the online portion of the questionnaire was completed. The whole process of subjective evaluation and physical measurements was completed in 10–13 minutes per workstation.

3. Measurement results and discussion

3.1. Ventilation performance

Outdoor fresh air is needed to maintain acceptable indoor air quality. The outdoor fresh air flow rate was measured using the decay tracer gas technique. The ventilation rate fell within 5 l/s/person, in building No. 5, and 93 l/s/person in building No. 4. Table 1 shows the ventilation rate in these buildings, both for cooling and heating seasons, and indicates that the ventilation rate in the majority of the buildings is much higher than the minimum 10 l/s/person recommended by the ASHRAE Standard 62-1989R.

Due to budget and time restraints, the decay tracer gas technique was used for the whole building, and not per station. The values represent the average air exchange rate for the whole set of workstations visited.

3.2. Indoor air contaminants

The concentration of the following contaminants was measured during the heating and cooling seasons: CO_2, formaldehyde, TVOC, and CO. The level of CO_2 concentration was lower than the maximum permitted in the ASHRAE Standard 62-89R, and was mainly between 450–650 ppm, in both seasons. In the investigated buildings, the CO_2 concentration was not a function of the ventilation rate; it is assumed that almost all the buildings were ventilated much higher than the ASHRAE Standard 62-89R recommended.

The formaldehyde concentration in these buildings varied between 74 ug/m^3 in a large majority of buildings and 2190 ug/m^3 in one building (during both cooling and heating seasons), Table 2. The concentration levels were significantly different during the heating and cooling seasons. No relationship was found between the ventilation rate and formaldehyde concentration during the cooling season. A relationship between these parameters was observed during the heating season; the HCHO concentration decreased as the ventilation rate increased.

The TVOC concentration level deviated between 36 ug/m^3 in building No. 6 in summer to 2590 ug/m^3 in the same building in winter, Table 3. In some buildings, the variation of TVOC from one workstation to another was

Table 1
Ventilation rate (l s p)

Building	Summer (l s p)	Winter (l s p)
1	15.9	18.7
2	15.9	51.0
3	20.1	33.9
4	89.5	27.2
5	5.9	5.9
6	12.2	10.1
7	NA	23.0
8	76.9	85.1
9	70.7	27.3
10	29.3	28.6
11	20.9	28.3

Table 2
HCOH concentration (ug/m³)

Building	Heating		Cooling	
	Low	High	Low	High
1	74	74	74	74
2	80	285	373	2190
3	74	182	855	2180
4	74	187	154	847
5	74	308	229	720
6	74	107	533	1100
7	74	74	302	787
8	74	74	136	615
9	74	74	74	369
10	74	74	113	352
11	74	74	120	646

Table 3
TVOC concentrations (ug m³)

Building	Heating		Cooling	
	Low	High	Low	High
1	36	93	585	1680
2	36	2670	905	3480
3	854	2000	990	2180
4	703	2120	672	1870
5	1080	2510	843	1740
6	36	351	2060	2700
7	58	144	851	2390
8	36	114	304	1350
9	36	106	183	744
10	37	109	519	1000
11	36	129	615	2150

more than 100%. In general, no correlation was found between the ventilation rate and TVOC concentration.

The CO concentration level was almost the same as the outdoor CO concentration within all workstations and in all buildings.

3.3. *Thermal comfort*

Detailed measurements of thermal comfort parameters were carried out at the exact physical position of the occupant in the workstation. The air and globe temperatures, as well as air velocity and turbulence, were measured at three heights (10, 60, 110 cm). The dew point temperature and vapour pressure were measured at one height (60 cm). Radiant asymmetry was also measured. This data was used to calculate the environmental and comfort indices: operative temperature, mean radiant temperature, effective temperature, predicted mean vote (PMV), predicted percentage of dissatisfied (PPD), and predicted percent dissatisfied due to draft (PD). Tables 4 and 5 show the statistical summaries of the indoor climate measurements made by CHARIOT during the cooling and heating seasons, respectively.

Mean air and radiant temperatures, averaged across the three heights, generally fell within 21 and 28 C for the cooling season, and within 20 and 28 C for the heating season. The variation in each individual building was very low; the standard deviation being less than 1°C. It was only from one building to the next that a large difference was seen.

Vertical air temperature gradients were, on average, about 0.67°C/m in the occupied zone; which is within the ASHRAE Standard 55-92 limit. Average relative humidities fell within 30 and 62%, in the cooling season, and within 10 and 39%, in the heating season.

Mean air speeds, averaged over the three heights, were quite low; they averaged 0.09 m/s and ranged from 0.04–0.24 m/s during the cooling season, and averaged 0.08 m/s and ranged from 0.03–0.29 m/s during the heating season. Similar variations were also observed from one workstation to another, within the same building. The turbulence intensities fell within 9 and 59% during the cooling season, and 6 and 66% during the heating season (average 32–33% for both seasons).

The ASHRAE Standard 55-1992 uses the operative temperature as the environmental parameter for evaluating global thermal comfort. The standard then defines a range of operative temperatures and humidities that are acceptable to 80% or more of the occupants. This range is mainly applicable to a sedentary activity, 1.2 met, with normal winter clothing, 0.8–1.2 clo, or summer clothing, 0.6–0.8 clo. The measured parameters were used to calculate the operative temperature using the procedure suggested in Chapter 13 of the ASHRAE 1993 Fundamentals [11], and the results were superimposed onto the standard's comfort psychometric charts for both the heating and cooling seasons.

Figure 1 shows that only 63.4% of the measurements fall within the standard's summer comfort zone (cooling season). The remaining 33.3% fall to the left of the comfort zone (within cooler temperatures). These percentages are based on the total amount sampled, and therefore are not average values. This means that in some buildings, there are less than 63.4% of the workstations that fall within the comfort zone.

Figure 1 also indicates that during the heating season, only 26.9% of the measurements fell within the winter comfort zone (heating). The remaining 73.1% fell below the 2.5°C dew-point level indicating the difficulty in humidifying buildings in the cold climate. Again, these percentages are based on the total amount sampled, so one might expect worse numbers in some buildings.

Tables 6 and 7 show a statistical summary of the thermal comfort indices for both seasons. On average, operative temperature, ET*, and SET values fell within the 22–24 C range. The PMV value fell within the −0.02–

Table 4
Results of indoor climatic data collected by CHARIOT during the summer hot season

Building	1	2	3	4	5	6	7	8	9	10	11	12	Total
Sample size	40	39	40	41	44	41	40	31	40	40	43	6	445
Air temperature (C) (average of 3 heights)													
Mean	23.3	23.3	22.7	24.0	25.1	23.4	23.1	26.4	23.7	25.5	23.4	23.5	23.9
Standard deviation	0.7	0.8	0.5	0.6	0.7	0.7	0.5	0.7	0.7	1.0	0.8	0.6	1.3
Minimum	21.5	21.2	21.7	21.7	23.4	21.7	22.1	24.6	22.1	23.3	21.9	22.6	21.2
Maximum	24.7	25.3	23.4	24.9	26.5	25.1	24.3	27.5	25.2	27.4	25.1	24.3	27.5
Mean radiat temperature (C) (calculated; average of 3 heights)													
Mean	22.9	22.5	22.0	23.4	24.8	22.7	22.6	25.3	23.0	24.8	23.0	22.7	23.3
Standard deviation	1.0	0.8	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.9	1.0	0.7	1.2
Minimum	20.9	20.7	21.2	22.3	23.4	21.5	21.6	23.6	21.6	23.0	21.7	22.0	20.7
Maximum	26.7	24.4	23.1	24.1	25.8	25.1	23.7	26.4	24.5	26.5	27.1	23.6	27.1
Plane radiat asymmetry (C) (above 1.1 m)													
Mean	1.4	0.6	1.0	0.6	0.8	0.6	0.9	0.7	0.6	1.3	1.5	0.9	0.9
Standard deviation	1.5	0.5	0.7	0.7	0.8	0.5	0.7	0.4	0.4	1.4	1.9	1.0	1.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0
Maximum	0.6	2.1	3.3	4.3	3.1	2.2	2.5	1.5	1.6	5.3	10.3	2.9	10.3
Dew point temperature (C) (at 0.6 m)													
Mean	8.9	8.9	13.8	12.5	13.8	8.9	14.7	11.9	10.2	10.4	9.9	10.2	11.3
Standard deviation	1.0	2.2	0.4	1.3	0.8	1.0	0.3	1.4	0.5	1.3	0.6	0.2	2.3
Minimum	7.5	5.4	13.0	9.9	12.5	7.1	14.0	10.2	9.5	8.0	9.3	10.0	5.4
Maximum	10.2	12.5	14.8	14.8	15.4	11.9	15.2	15.1	11.0	12.0	11.3	10.5	15.4
Relative humidity (%) (calculated)													
Mean	39.5	39.7	56.7	48.3	49.2	39.3	58.7	40.2	42.1	38.6	42.1	42.5	45.0
Standard deviation	3.6	5.3	2.0	4.3	2.7	2.8	1.5	3.7	1.6	4.5	3.1	1.5	7.6
Minimum	33.0	29.5	53.5	39.5	45.0	34.3	54.7	36.9	37.2	32.3	37.7	40.3	29.5
Maximum	45.9	47.8	62.2	55.5	54.0	52.2	61.4	49.3	44.6	45.7	50.4	44.8	62.2
Vapor pressure (kPa) (at 0.6 m)													
Mean	1.1	1.2	1.6	1.5	1.6	1.1	1.7	1.4	1.2	1.3	1.2	1.2	1.4
Standard deviation	0.1	0.2	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.2
Minimum	1.0	0.9	1.5	1.2	1.5	1.0	1.6	1.2	1.2	1.1	1.2	1.2	0.9
Maximum	1.3	1.5	1.7	1.7	1.8	1.4	1.7	1.7	1.3	1.4	1.3	1.3	1.8
Air velocity (m s) (average of 3 heights)													
Mean	0.10	0.11	0.09	0.08	0.11	0.08	0.08	0.07	0.09	0.08	0.09	0.09	0.09
Standard deviation	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.01	0.02	0.02	0.02	0.03	0.03
Minimum	0.06	0.06	0.05	0.05	0.06	0.05	0.04	0.05	0.06	0.05	0.06	0.06	0.04
Maximum	0.21	0.22	0.14	0.24	0.16	0.19	0.11	0.11	0.13	0.14	0.14	0.13	0.24
Turbulence intensity (%) (Calculated; average of 3 heights)													
Mean	31.6	33.1	31.2	32.0	33.6	30.0	33.6	33.5	34.3	33.0	32.1	34.5	32.6
Standard deviation	5.7	5.8	4.7	8.5	5.8	6.0	6.0	7.0	7.3	6.8	4.8	7.8	6.4
Minimum	21.0	22.0	23.0	9.0	22.0	20.0	20.0	22.0	23.0	20.0	22.0	23.0	9.0
Maximum	49.0	43.0	44.0	55.0	45.0	45.0	49.0	49.0	59.0	56.0	44.0	46.0	59.0

−0.03 range; indicating marginally cooler-than-neutral conditions. The corresponding PPD ranged from 13.1–13.6%.

In evaluation of the operative temperature and defining the ASHRAE comfort zone for indoor air studies, two assumptions are made: activity level and clothing value. To verify the validity of the assumptions, the occupants were asked to identify their activity level up to one hour prior to filling in the questionnaire. On average, the activity level was 1.2 met in both heating and cooling seasons.

The clothing insulation of the occupant was evaluated using the garment values published in ASHRAE Standard 55-1992. The intrinsic clothing value averaged 0.62 clo (males) and 0.53 clo (females) in the summer (about 16% higher than the 0.5 clo assumed in the standard), averaged 0.93 clo (males) and 0.81 clo (female) in the winter (about 3% lower than the 0.9 clo assumed in the standard).

The garment clo values of the occupants were then corrected by adding the chair clo values. The correction value was proportional to the amount of chair surface area in contact with the body (chair type). This modification increased the average level by 0.22 clo (males) and 0.09 clo (females) in the summer and 0.26 clo (males) and 0.14 clo (females) in the winter; increasing the insulation values to 0.84 clo (males) and 0.62 clo (females) in the summer and 1.19 clo (males) and 0.95 clo (females)

Table 5
Results of indoor climatic data collected by CHARIOT during the winter cold season

Building	1	2	3	4	5	6	7	8	9	10	11	Total
Sample size	39	38	39	41	44	40	41	30	40	39	40	431
Air temperature (C) (average of 3 heights)												
Mean	22.9	23.2	23.2	22.7	23.1	22.8	23.2	22.7	23.7	22.2	23.3	23.0
Standard deviation	0.4	1.0	0.5	0.5	0.7	0.6	0.8	1.0	0.7	1.0	0.7	0.8
Minimum	21.9	21.1	21.9	21.3	21.7	21.2	21.0	21.3	22.2	20.3	21.4	20.3
Maximum	23.9	25.1	24.2	23.7	24.6	23.8	26.3	24.6	24.9	23.7	24.5	26.3
Mean radiat temperature (C) (calculated: average of 3 heights)												
Mean	22.7	22.6	22.5	21.5	22.4	21.8	22.2	21.8	22.6	21.6	22.9	22.2
Standard deviation	1.2	0.9	0.5	0.5	0.6	0.5	0.7	0.9	0.6	1.0	0.5	0.9
Minimum	21.6	20.8	21.2	19.8	21.2	20.7	20.1	20.2	20.8	19.5	21.4	19.5
Maximum	28.3	24.9	23.6	22.4	23.8	22.8	23.7	23.7	23.7	23.3	23.8	28.3
Plane radiat asymmetry (C) (above 1.1 m)												
Mean	1.2	1.2	0.6	1.0	1.2	0.7	1.2	0.9	1.4	1.5	0.8	1.1
Standard deviation	1.4	1.6	0.4	1.0	1.0	0.5	1.0	0.7	1.1	1.4	0.6	1.1
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Maximum	5.9	10.0	1.5	3.9	4.2	2.2	4.1	3.0	4.0	5.7	2.6	10.0
Dew point temperature (C) (at 0.6 m)												
Mean	6.5	2.5	1.4	1.4	5.5	3.9	0.7	5.6	6.2	1.2	5.1	3.6
Standard deviation	2.2	2.0	0.8	0.6	2.3	0.6	0.5	1.6	1.3	0.8	0.9	2.5
Minimum	1.3	0.3	0.2	0.1	0.9	2.4	0.1	0.8	3.9	0.1	2.1	0.1
Maximum	9.1	6.8	3.2	2.7	8.8	5.1	2.0	7.8	8.9	4.6	6.7	9.1
Relative humidity (%) (calculated)												
Mean	16.5	17.8	23.5	19.5	13.7	28.8	22.4	32.7	12.3	20.8	30.5	21.4
Standard deviation	8.0	3.0	1.2	1.0	2.8	1.2	1.4	3.5	1.0	1.2	1.7	7.0
Minimum	10.0	11.7	21.5	16.9	10.0	26.0	19.9	21.5	9.7	17.3	26.9	9.7
Maximum	31.5	23.2	26.7	22.9	20.7	31.8	25.9	39.2	14.0	23.3	34.8	39.2
Vapor pressure (kPa) (at 0.6 m)												
Mean	0.5	0.5	0.7	0.5	0.4	0.8	0.6	0.9	0.4	0.6	0.9	0.6
Standard deviation	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.2
Minimum	0.3	0.3	0.6	0.5	0.3	0.7	0.6	0.6	0.3	0.4	0.7	0.3
Maximum	0.9	0.7	0.8	0.6	0.6	0.9	0.7	1.1	0.4	0.7	1.0	1.1
Air velocity (m s) (average of 3 heights)												
Mean	0.10	0.11	0.09	0.06	0.08	0.07	0.08	0.07	0.08	0.07	0.09	0.08
Standard deviation	0.03	0.05	0.03	0.01	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.03
Minimum	0.06	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.03	0.04	0.05	0.03
Maximum	0.17	0.24	0.20	0.10	0.12	0.12	0.29	0.16	0.15	0.16	0.19	0.29
Turbulence intensity (%) (calculated: average of 3 heights)												
Mean	33.0	32.6	29.3	29.6	31.3	30.8	32.0	34.9	30.9	33.4	31.4	31.8
Standard deviation	5.8	5.5	4.6	5.5	4.8	6.8	7.1	8.4	9.1	9.2	4.9	6.8
Minimum	18.0	21.0	21.0	20.0	21.0	16.0	12.0	19.0	6.0	18.0	21.0	6.0
Maximum	44.0	44.0	44.0	42.0	42.0	46.0	48.0	52.0	54.0	66.0	46.0	66.0

in the winter. The clothing insulation values were much higher (about 0.11 clo) for the males than for the females, in both seasons. This difference was even greater when the effect of chairs was included (about 0.23 clo).

Some of the thermal environmental and comfort indices were re-evaluated by including the chair insulation values to the clothing values. The new indices are shown as the last four rows of Tables 6 and 7. This translates into a 1.2–1.3 C increase in SET, and a 0.2–0.3% increase in PMV index, which corresponds to a 2.0–2.4% decrease in PPD index.

The PMV index predicted neutralities well, with and without the effect of chair insulation. However, large discrepancies were found as the temperatures progressed away from neutral. At the lower margin of the winter comfort zone (20 C–23.5 C), the PMV index differed by about 1.5 sensation units. Similarly, at the higher margin of the summer comfort zone (23 C–26 C), the PMV index differed by about 1 sensation unit. This indicated that the observed mean vote's sensitivity to temperature was more pronounced than theory (PMV) predicted.

3.4. *Energy performance*

In mechanically ventilated buildings, the energy required to heat, cool, condition, and move the air amounts to from 30%–50% of the total building energy consumption. It is therefore, a common perception that

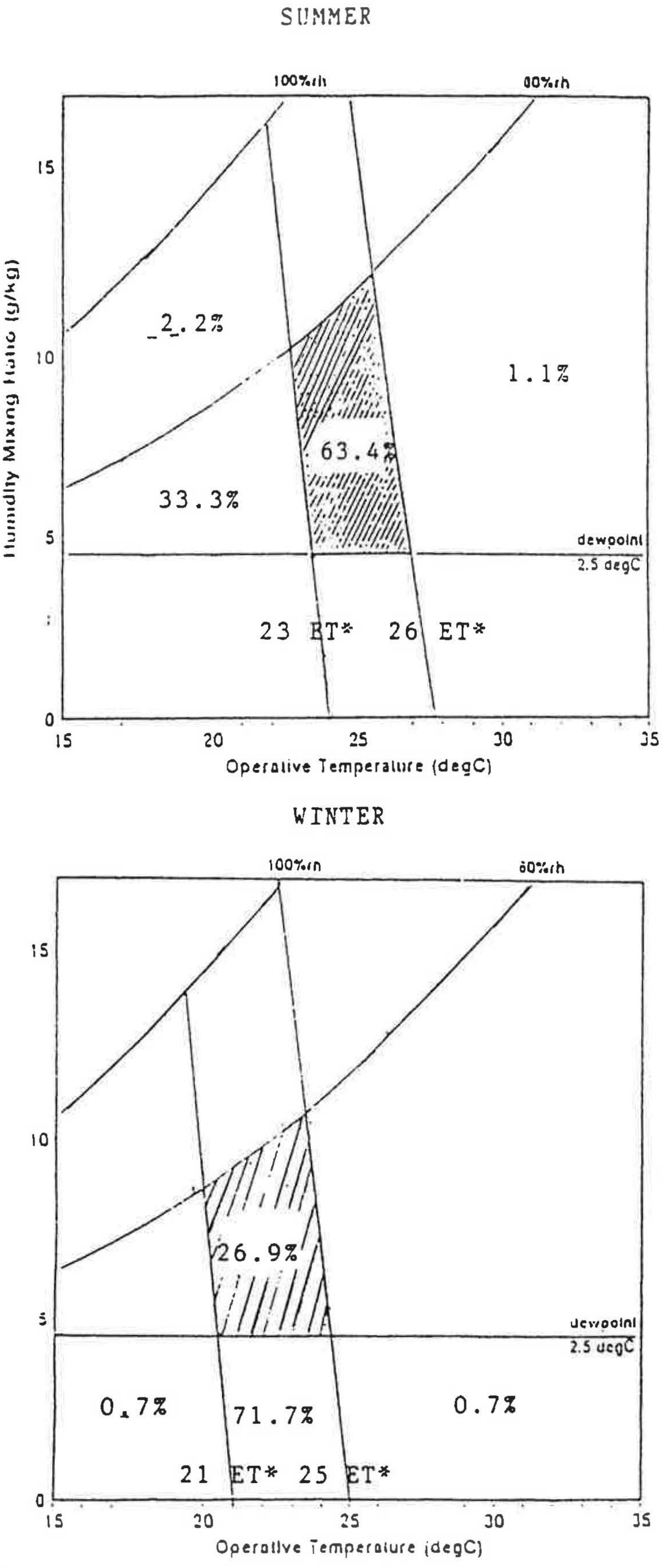


Fig. 1. Results of indoor climate data (CHARIOT) for both summer hot and winter cold seasons on the ANSI ASHRAE Standard 55-1992 chart.

Table 6
Statistical summary of calculated indoor climatic and thermal confort indices (winter cold season)

Building[a] Sample size	1 39	2 38	3 39	4 41	5 44	6 40	7 41	8 30	9 40	10 39	11 40	Total 431
Operative temperature (C)												
Mean	22.8	22.9	22.9	22.1	22.8	22.3	22.7	22.3	23.2	21.9	23.1	22.6
Standard deviation	0.7	0.9	0.5	0.5	0.6	0.5	0.7	1.0	0.6	1.0	0.6	0.8
Minimum	21.9	21.1	21.6	20.5	21.5	21.1	20.5	20.9	22.0	19.9	21.5	19.9
Maximum	25.9	25.0	23.8	23.0	24.2	23.3	23.9	24.2	24.3	23.3	24.1	25.9
ET* (C)												
Mean	22.2	22.2	22.3	21.6	22.1	21.9	22.1	22.0	22.4	21.4	22.7	22.1
Standard deviation	0.8	0.9	0.5	0.5	0.6	0.5	0.7	0.9	0.7	0.9	0.6	0.8
Minimum	20.9	20.4	21.3	20.2	20.1	20.9	20.2	20.6	20.1	19.5	21.3	19.5
Maximum	24.8	24.5	23.5	22.5	23.7	22.9	23.6	23.8	23.7	22.9	23.8	24.8
SET* (C)												
Mean	24.6	25.0	25.0	23.6	24.3	24.1	24.1	23.8	24.5	24.5	25.0	24.4
Standard deviation	1.8	2.4	2.1	2.1	2.1	1.9	1.9	2.2	2.3	2.1	2.5	2.2
Minimum	21.0	20.5	20.8	20.0	21.0	21.2	20.7	19.8	20.7	20.7	18.9	18.9
Maximum	28.1	29.8	29.7	27.7	29.4	29.8	29.0	29.4	30.5	29.3	30.4	30.5
DISC (from 2-node)												
Mean	0.1	0.2	0.1	−0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.1
Standard deviation	0.3	0.4	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.5	0.3
Minimum	−0.3	−0.3	−0.3	−0.4	−0.4	−0.2	−0.4	−0.4	−0.3	−0.3	−0.6	−0.6
Maximum	0.8	1.3	1.1	0.6	1.1	1.1	1.0	1.2	1.5	1.1	1.5	1.5
PMVF												
Mean	−0.2	−0.1	−0.1	−0.5	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.1	−0.2
Standard deviation	0.5	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.7	0.6
Minimum	−1.6	−1.9	−1.6	−1.9	−1.5	−1.2	−1.6	−1.9	−1.4	−1.5	−2.7	−2.7
Maximum	0.7	0.9	0.7	0.6	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.9
PPDF (%)												
Mean	11.7	12.9	12.0	17.6	13.8	12.4	13.6	14.6	13.9	12.7	14.6	13.6
Standard deviation	9.8	13.6	10.6	16.7	11.7	8.4	11.7	16.5	9.7	10.2	15.7	12.4
Minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Maximum	55.0	71.0	56.0	70.0	51.0	35.0	58.0	73.0	46.0	51.0	97.0	97.0
Predicted draught dissatisfaction (%)												
Mean	8.0	8.5	6.3	2.7	5.0	3.3	5.0	3.8	3.9	4.7	6.3	5.2
Standard deviation	3.1	5.4	3.0	2.1	2.8	3.1	3.8	3.8	3.0	3.8	3.2	3.8
Minimum	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	16.3	23.5	16.1	8.0	10.9	10.5	20.2	15.7	11.1	16.3	16.9	23.5
SET (C) (including chair insulation)												
Mean	25.9	26.2	26.6	24.9	25.5	25.3	25.1	25.3	25.6	26.1	26.1	25.7
Standard deviation	1.9	2.7	2.3	2.1	2.2	2.2	2.2	2.3	2.4	2.2	2.7	2.3
Minimum	21.0	20.5	22.4	21.4	21.4	21.6	20.7	21.2	21.5	22.4	20.3	20.3
Maximum	30.5	31.2	31.3	29.3	30.9	31.4	30.6	31.6	32.1	30.8	31.6	32.1
DISC (from 2-node) (including chair insulation)												
Mean	0.2	0.4	0.4	0.1	0.2	0.2	0.1	0.2	0.2	0.3	0.4	0.2
Standard deviation	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5
Minimum	−0.3	−0.3	−0.2	−0.3	−0.3	−0.2	−0.4	−0.3	−0.2	−0.2	−0.4	−0.4
Maximum	1.5	1.8	1.7	1.0	1.6	1.6	1.4	1.9	2.1	1.6	1.9	2.1
PMVF (including chair insulation)												
Mean	0.1	0.1	0.2	−0.2	0.0	−0.1	−0.1	0.0	0.0	0.1	0.1	0.0
Standard deviation	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.6	0.5
Minimum	−1.6	−1.9	−1.0	−1.3	−1.4	−1.0	−1.6	−1.4	−1.1	−1.0	−2.0	−2.0
Maximum	1.0	1.1	0.9	0.7	0.9	0.9	0.9	1.1	0.9	1.0	1.0	1.1
PPDF (C) (including chair insulation)												
Mean	10.2	13.1	10.7	11.6	11.2	9.9	12.0	10.9	10.9	9.7	13.4	11.2
Standard deviation	9.8	13.7	5.2	8.3	8.3	5.6	11.1	9.5	6.5	5.6	12.4	9.1
Minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Maximum	55.0	71.0	26.0	41.0	48.0	25.0	58.0	43.0	29.0	26.0	79.0	79.0

Table 7
Statistical summary of calculated indoor climatic and thermal comfort indices (summer/hot season)

Building Sample size	1 40	2 39	3 40	4 41	5 44	6 41	7 40	8 31	9 40	10 40	11 43	12 6	Total 445
Operative temperature (°C)													
Mean	23.1	22.9	22.3	23.7	24.9	23.1	22.8	25.8	23.3	25.1	23.2	23.1	23.6
Standard deviation	0.8	0.8	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.9	0.9	0.6	1.2
Minimum	21.3	21.0	21.4	22.2	23.5	21.7	21.9	24.1	21.8	23.2	21.9	22.3	21.0
Maximum	25.6	24.6	23.1	24.5	26.1	25.1	24.0	26.9	24.9	26.9	25.6	23.9	26.9
ET* (°C)													
Mean	23.0	22.8	22.4	23.6	24.9	22.9	22.9	25.6	23.2	24.9	23.1	23.0	23.5
Standard deviation	0.8	0.8	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.8	0.9	0.6	1.2
Minimum	21.2	20.9	21.6	22.2	23.5	21.6	22.0	23.7	21.7	23.1	21.9	22.2	20.9
Maximum	25.6	24.5	23.2	24.4	26.5	25.0	24.1	26.6	24.6	26.5	25.7	23.7	26.6
SET* (°C)													
Mean	23.3	23.1	23.0	23.0	24.0	23.1	22.7	25.6	23.5	24.3	23.5	24.0	23.5
Standard deviation	1.8	2.0	2.3	1.1	1.2	2.3	1.7	1.7	2.0	1.4	1.5	1.9	1.9
Minimum	20.8	19.4	20.2	21.2	21.9	19.6	20.1	22.9	19.8	21.3	20.4	21.8	19.4
Maximum	27.2	29.2	28.6	25.6	27.4	30.4	27.7	30.8	29.2	28.1	26.7	27.1	30.8
DISC (from 2-node)													
Mean	−0.1	−0.1	0.0	−0.1	0.0	−0.1	−0.1	0.2	0.0	0.0	−0.1	0.0	0.0
Standard deviation	0.2	0.3	0.3	0.1	0.2	0.3	0.2	0.4	0.3	0.2	0.1	0.2	0.2
Minimum	−0.3	−0.4	−0.3	−0.3	−0.2	−0.5	−0.4	−0.2	−0.4	−0.2	−0.3	−0.2	−0.5
Maximum	0.6	1.1	0.8	0.1	0.6	1.4	0.7	1.6	1.0	0.8	0.4	0.5	1.6
PMVF													
Mean	−0.4	−0.4	−0.4	−0.4	−0.1	−0.5	−0.4	0.3	−0.4	0.0	−0.3	−0.2	−0.3
Standard deviation	0.5	0.6	0.6	0.4	0.4	0.7	0.5	0.5	0.6	0.5	0.5	0.4	0.6
Minimum	−1.7	−2.2	−1.5	−1.3	−1.3	−2.1	−1.8	−0.9	−2.0	−1.0	−1.5	−0.7	−2.2
Maximum	0.5	0.7	0.7	0.4	0.7	0.9	0.8	1.2	0.9	0.9	0.5	0.4	1.2
PPDF (%)													
Mean	14.3	15.2	15.7	11.0	8.7	18.3	13.5	11.5	15.0	9.8	12.3	8.8	13.1
Standard deviation	12.8	16.4	12.5	8.7	6.6	20.1	12.2	7.9	14.5	5.7	10.9	3.9	12.5
Minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Maximum	60.0	84.0	53.0	42.0	40.0	81.0	68.0	33.0	74.0	24.0	53.0	14.0	84.0
Predicted draught dissatisfaction (%)													
Mean	7.6	8.2	6.4	5.0	6.6	4.5	5.4	2.3	5.4	4.3	6.0	6.2	5.7
Standard deviation	3.1	4.7	2.5	5.5	2.6	3.7	1.9	1.7	1.9	2.7	2.3	2.9	3.5
Minimum	2.3	2.2	0.0	0.0	1.8	0.0	2.4	0.0	2.1	0.0	2.0	2.2	0.0
Maximum	17.6	26.3	11.8	35.3	12.9	16.8	9.8	7.8	9.9	11.3	12.1	10.1	35.3
SET (°C) (including chair insulation)													
Mean	24.5	24.3	24.5	24.2	25.1	24.4	23.9	26.7	24.5	25.5	24.7	24.5	24.7
Standard deviation	2.1	2.4	2.8	1.3	1.5	2.7	2.1	2.0	2.4	1.7	1.6	1.9	2.2
Minimum	20.8	20.4	20.4	21.8	21.9	19.8	20.1	22.9	19.8	21.3	21.8	21.8	19.8
Maximum	28.7	31.1	31.0	27.2	28.6	32.2	30.5	30.8	31.2	30.2	28.6	27.1	32.2
DISC (from 2-node) (including chair insulation)													
Mean	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.4	0.1	0.2	0.1	0.1	0.1
Standard deviation	0.3	0.4	0.5	0.1	0.3	0.4	0.3	0.5	0.5	0.3	0.3	0.3	0.4
Minimum	−0.3	−0.3	−0.2	−0.2	−0.2	−0.5	−0.4	−0.2	−0.4	−0.2	−0.2	−0.2	−0.5
Maximum	0.9	1.7	1.6	0.5	0.9	2.0	1.6	1.7	1.7	1.4	0.8	0.5	2.0
PMVF (including chair insulation)													
Mean	−0.1	−0.1	−0.1	−0.1	0.1	−0.2	−0.1	0.5	−0.1	0.2	−0.1	−0.1	0.0
Standard deviation	0.5	0.6	0.6	0.3	0.4	0.7	0.5	0.5	0.6	0.4	0.4	0.4	0.5
Minimum	−1.4	−1.3	−1.0	−0.8	−1.3	−2.1	−1.8	−0.9	−2.0	−0.8	−1.1	−0.7	−2.1
Maximum	0.7	1.0	0.9	0.7	0.9	1.0	1.0	1.2	1.1	1.1	0.7	0.4	1.2
PPDF (°C) (including chair insulation)													
Mean	10.8	12.6	11.6	7.5	8.6	14.2	10.9	15.3	12.9	10.2	9.1	8.0	11.1
Standard deviation	8.1	9.9	6.3	3.6	6.5	15.0	12.2	9.7	13.8	6.0	5.6	3.2	9.5
Minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Maximum	47.0	41.0	27.0	18.0	40.0	79.0	68.0	37.0	74.0	31.0	28.0	14.0	79.0

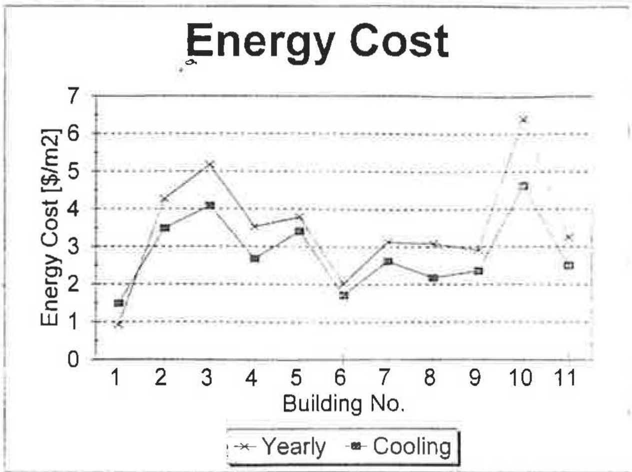


Fig. 2. Energy consumption.

energy saving will result in deterioration of indoor air. Figure 2 shows that energy cost varies from building to building. The average total energy cost per gross air-conditioned area fell between 0.92–6.4 $/m^2/year. There is no apparent correlation between the ventilation rate and total energy cost. There are many reasons for this incoherent result.

The energy required for ventilation is only part of the total energy consumption; the other consumptions include conduction losses through the building envelope, lighting, elevators, office equipment (computers, fax machines, etc). The investigated buildings also used a wide variety of HVAC system types, and energy conservation measures such as heat recovery systems. As well, they used a variety of energy sources: electricity, gas, oil, etc. It was not possible to differentiate the actual amount of energy used solely for the ventilation from the rest of the consumption.

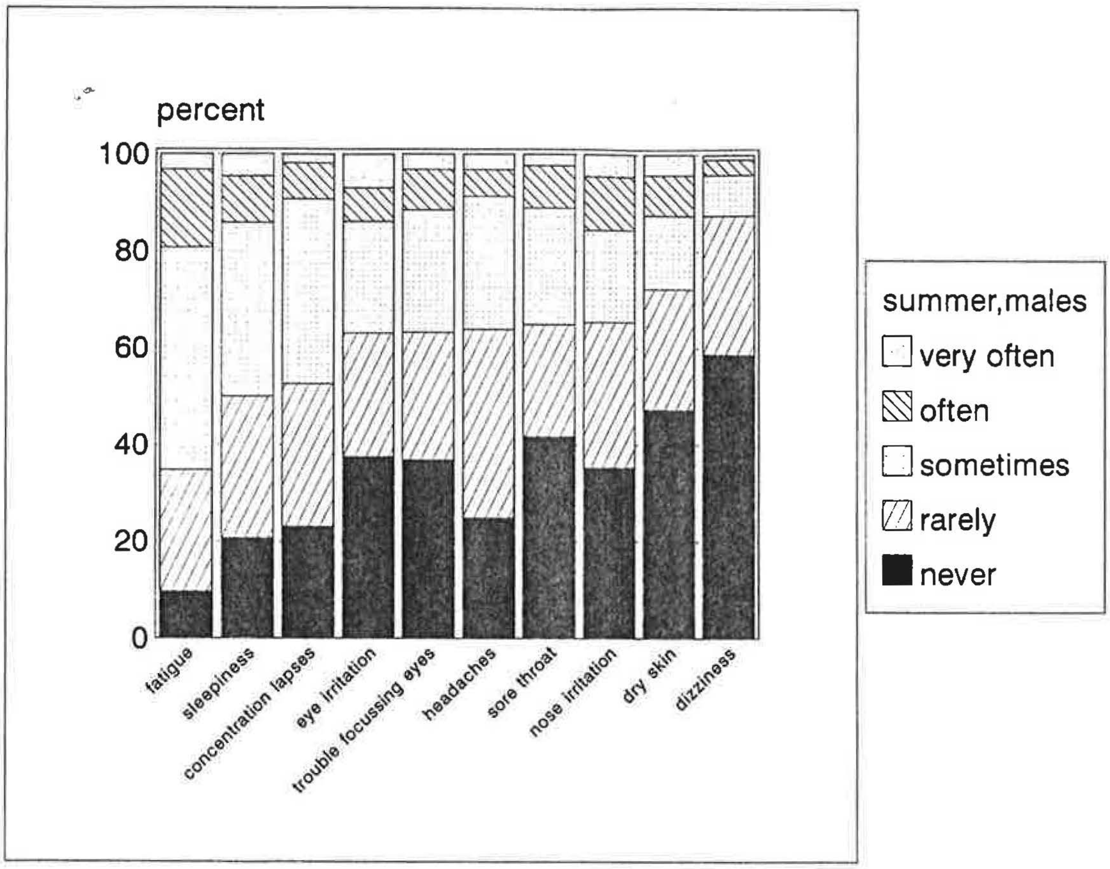
4. Occupants' perception

4.1. Indoor air quality

Ten symptoms were rated by the occupants to assess their health status. The most frequently occurring symptom was 'fatigue', in both seasons; and the least occurring symptom was 'dizziness', in both seasons, Figs 3 and 4. There was also a difference in gender: females noted 'dry skin' and 'headaches' more often than males. Males noted 'sore throats' and 'eye irritation' more often than females. Furthermore, occurrences of 'sore throat' increased with age whereas 'fatigue' and 'sleepiness' decreased with age. There is a definite seasonal pattern in the data; 'dry skin', 'nose irritation', and 'sore throats' were more frequent during the winter/cold season, as was to be expected. However, 'concentration lapses', 'trouble focusing eyes', 'sleepiness', and 'headaches' were more frequent during the summer/hot season. Reports of headache were more prevalent in deep, open-plan office spaces than in private offices. The Pearson Correlation Coefficient between the health index and the perception of indoor air quality was moderately negative ($r = -0.33$; $P < 0.01$; $df = 874$). In other words, the more dissatisfied with the indoor air quality was the occupant, the more often the occupant self-reported health symptoms. The Pearson Correlation Coefficient between the actual, measured relative humidity and 4 health symptom frequencies (sore throat, nose irritation, eye irritation, and skin irritation) were quite weak (r = -0.10, -0.12, 0.06, and -0.17, respectively; $P < 0.01$; $df = 870$).

The health symptom frequency question was investigated for correlations with several factors. The correlations between the health index and the online section of the questionnaire yielded only moderately negative relationships with ratings of air movement acceptability ($r = -0.28$; $P < 0.0001$; $df = 875$), and with ratings of general comfort ($r = -0.22$; $P < 0.0001$; $df = 876$). This suggested that subjects who recorded poor health were slightly more likely to rate the air movement as less acceptable and to rate their general comfort as less comfortable than those who recorded good health. Work area satisfaction with temperature, air quality, ventilation and air circulation, and overall comfort all yielded moderately negative dependencies ($-0.24 < r < -0.33$; $P < 0.0001$; $df = 875$). Perceived overall comfort, air movement acceptability, and perceived humidity all yielded moderately negative dependencies ($-0.26 < r < -0.31$; $P < 0.0001$; $df = 876$). The satisfaction with level of control also yielded a moderately negative dependency ($r = -0.25$; $P < 0.0001$; $df = 874$). Finally, environmental sensitivity to cold, too little air movement, and poor air quality yielded moderately positive dependencies ($0.20 < r < 0.26$; $P < 0.0001$; $df = 875$).

The majority of the respondents rated the overall level of air movement as being 'too little' (the females voted thus more often that the males), Fig. 5. The responses were almost evenly split between the acceptable and unacceptable sides of the ratings scale during both seasons. Therefore, not only are the air movement levels not right, they are not acceptable by almost half of the sample. The subjects were asked to assess the air movement at their workstations, in terms of acceptability and preference, at the time of the measurements. The mean air movement acceptability ratings were classified as 'slightly acceptable' in both seasons. The 'very unacceptable' ratings of air movement increased with temperature (a linear dependence of air movement dissatisfaction is found). More than half of all subjects wanted 'more air movement', and this for both seasons. The air movement preferences were binned with operative temperature measured at the same time. The linear regression fit to the data suggested a linear dependence of air velocity preference with temperature. At about 23 C or higher,



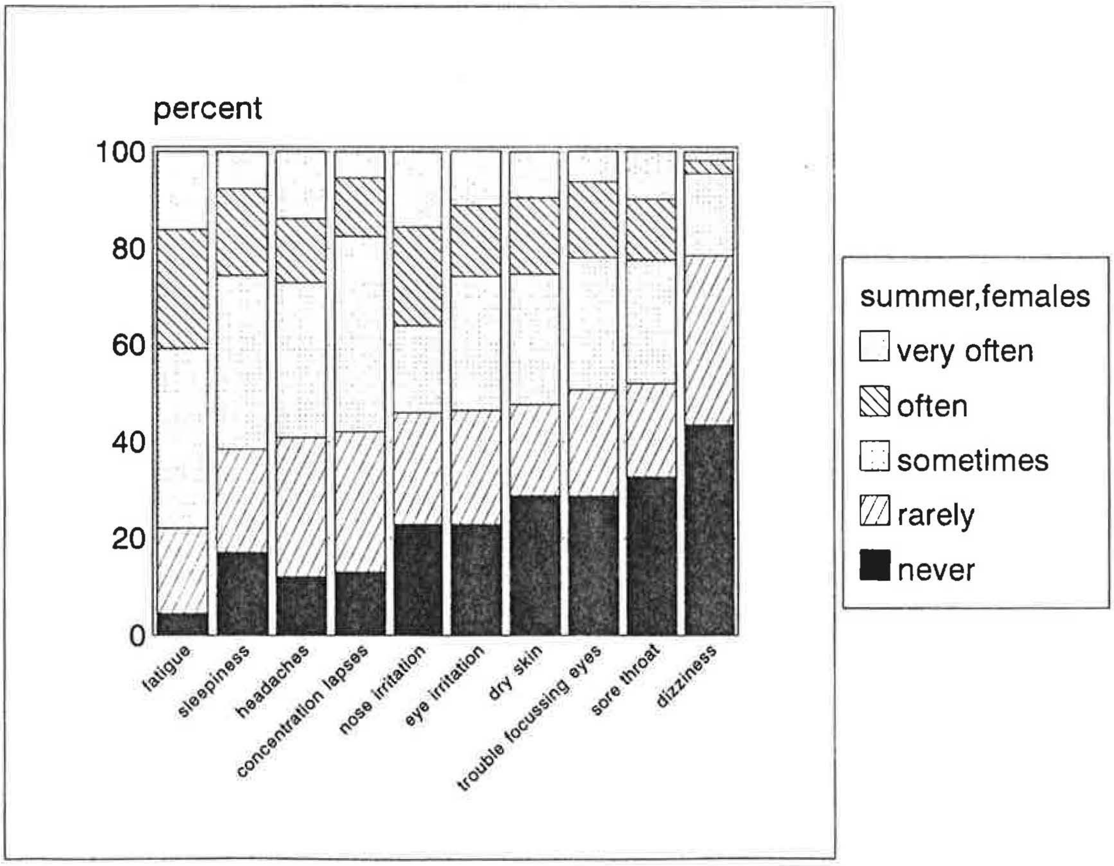
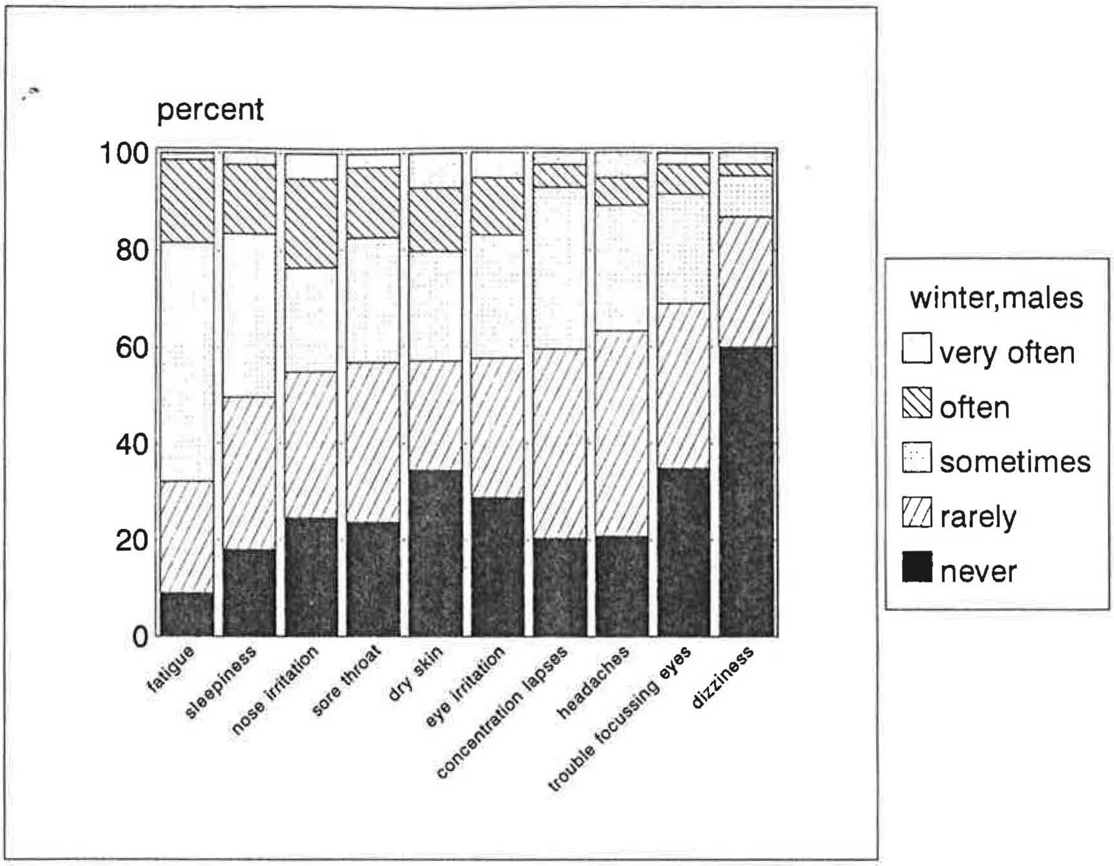


Fig. 3. Self-reported health symptom frequency (summer season).



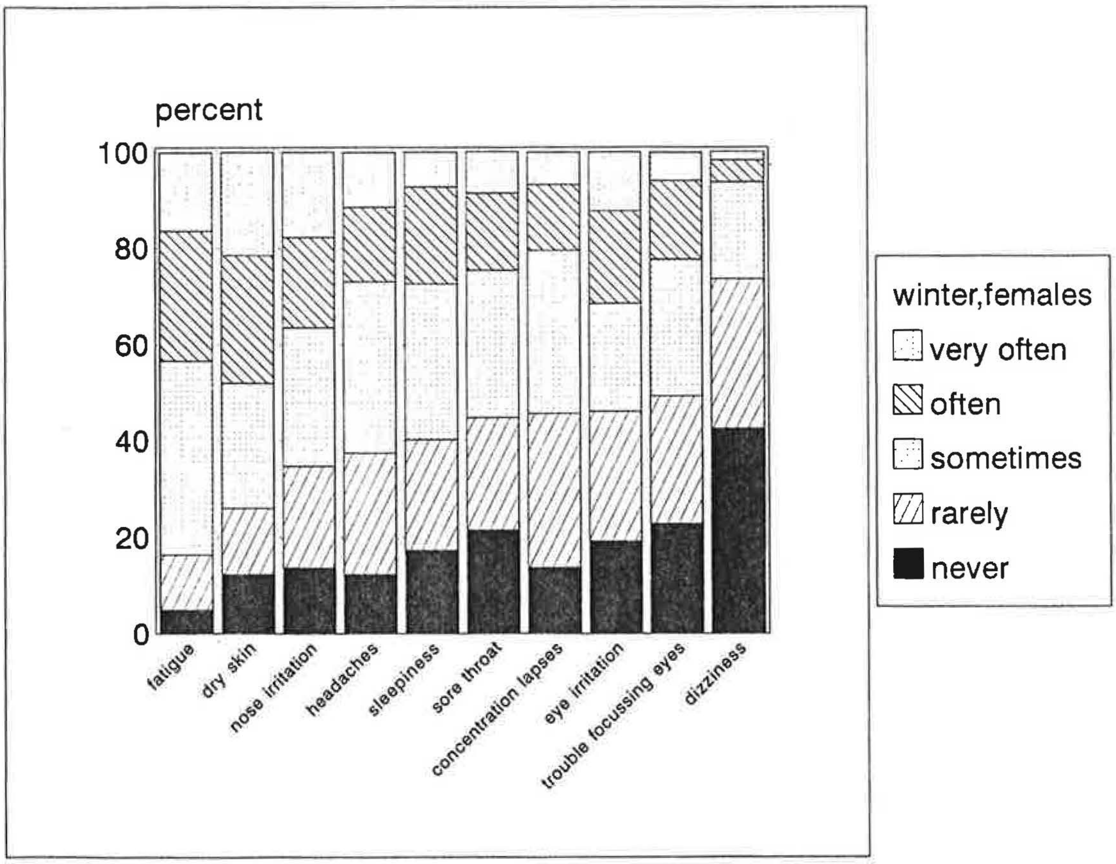
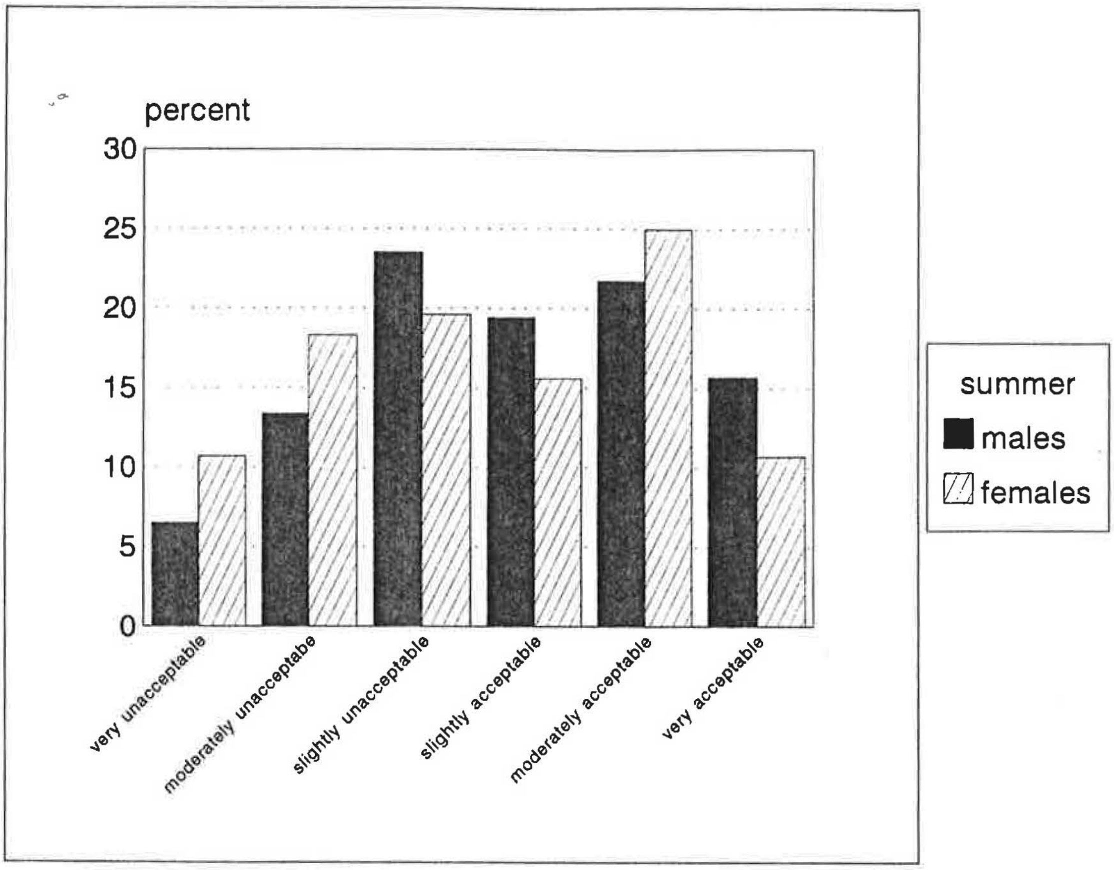


Fig. 4. Self-reported health symptom frequency (Winter season).



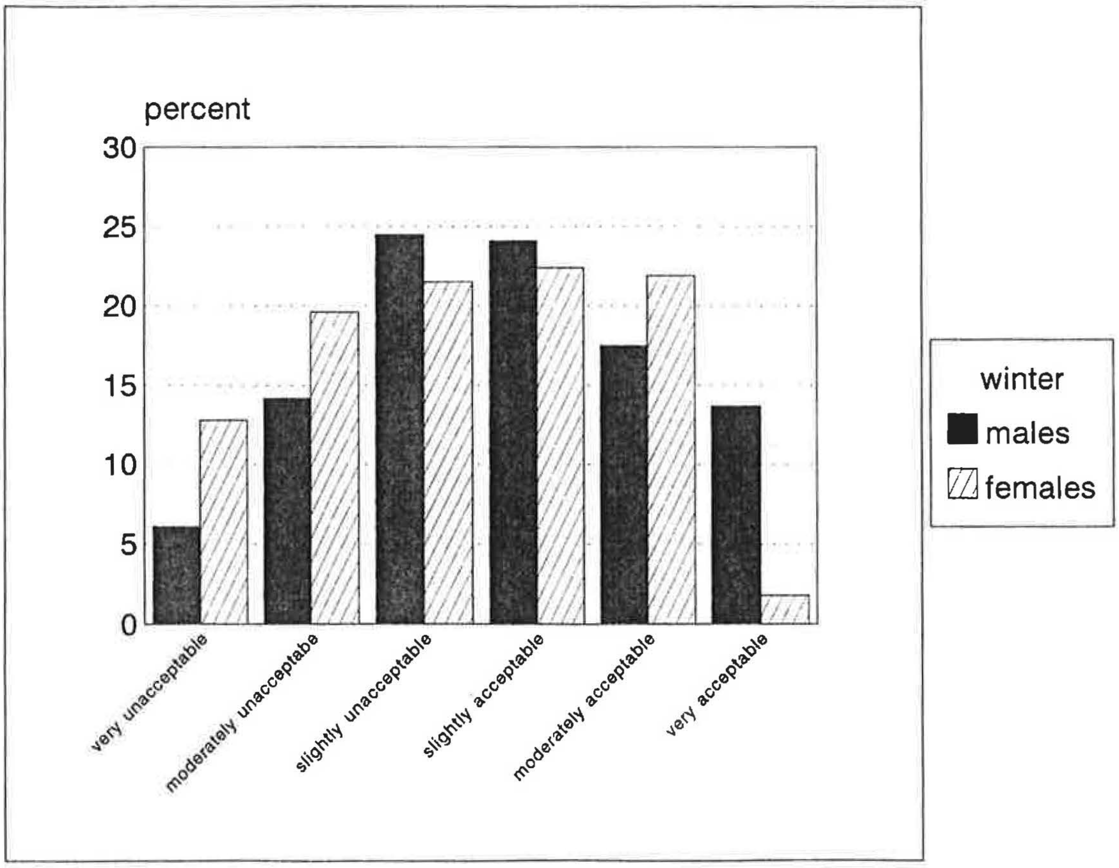


Fig. 5. Ratings of overall office air movement acceptability.

more than half of the respondents were calling for greater air speeds than they were experiencing at the time (<0.10 m/s). At the extremities of the ASHRAE Standard 55-92 comfort zone for both seasons (20–26°C), from 25–80% of the occupants wanted higher air velocities. Further analysis of the data showed that the warmer the operative temperature, the more people wanted air speeds higher than those being provided at their workstation. The Pearson Correlation Coefficient between the satisfaction with the air quality and preferred air movement yielded a moderately positive dependence ($r = +0.26$; $P < 0.0001$; $df = 860$). This suggests that the occupants were more dissatisfied with indoor air quality when they preferred more air movement (i.e., they felt too little air movement), and they were more satisfied with the air quality when they wanted less air movement (i.e., they felt too much air movement). In other words, the higher the perceived air movement, the greater the satisfaction with air quality.

The occupants' environmental sensitivity was rated using a group of eight questions. The occupants felt they were most sensitive to poor air quality, low air movement, and heat, and least sensitive to high air movement. The Pearson Correlation Coefficient between the satisfaction with air quality and 4 measured parameters (relative humidity, temperature, velocity, and turbulence) was quite weak ($r = 0.08, -0.19, 0.16$, and 0.08 respectively; $P < 0.01$; $df = 874$).

4.2. Thermal comfort

The occupants were asked to rate their 'overall office comfort'. The majority of the sample was 'moderately comfortable'. The overall thermal characteristics, such as temperature, humidity, air movement levels and acceptability were assessed. The majority response in both seasons was 'slightly warm' for the males, and 'slightly cool' for the females. In the case of humidity, the majority response in both seasons was 'slightly dry'; with females voting on the 'dry' side more often than males. However, as shown in Fig. 6, the percentage of 'dry' responses increased during the winter/cold season, as was to be expected. The Pearson Correlation Coefficient between perceived relative humidity and measured relative humidity yielded a moderately positive dependence ($r = 0.30$; $P < 0.01$; $df = 876$). A total of 129 subjects (out of 872) voted directly that their thermal environments were unacceptable (67 in the summer/hot season and 62 in the winter/cold season). Of this group of dissatisfied subjects, more than 80% (70% in the summer/hot season and 94% in the winter/cold season) were in environments that fulfilled the ANSI/ASHRAE Standard 55-1992 whole-body comfort zone criteria, with respect to operative temperature. Of the 743 subjects who voted directly that their thermal environments were acceptable (374 in the summer/hot season and 369 in the winter/cold season), 22% were actually in conditions outside of the ANSI/ASHRAE Standard 55-1992 comfort zone (41% in the summer/hot season and 3% in the winter/cold season). From this, it seems that the votes coincided with the comfort zone the best during the winter season, and that only for those voting acceptable thermal environments. In summary, 69% of those surveyed agreed with the ANSI/ASHRAE Standard 55-1992 comfort zone (54% in the summer/hot season and 84% in the winter/cold season). Only 20 subjects (summer/hot season) and 4 subjects (winter/cold season) voted that their thermal environments were unacceptable and were in effect in conditions outside of the ANSI/ASHRAE Standard 55-1992 comfort zone.

Another question in the survey asked the occupants their thermal preference; whether they would prefer to feel warmer or cooler. Their responses were binned into 0.5°C ET* intervals. A probit analysis was performed on the resulting percentages. It was assumed that the point of intersection between the 'want cooler' and 'want warmer' probit models represents the preferred temperature. In the summer/hot season, the preferred temperature was 23°C ET*, and 22°C ET* in the winter/cold season. At this optimum temperature, in the summer/hot season, 32% of the occupants indicated a desire for either warmer or cooler conditions. In the winter/cold season, 40% of the occupants indicated a desire for either warmer or cooler conditions [5].

4.3. Personal control

More than 60% of the occupants responded that they had no control over their thermal environment of their workstation, Figs 7 and 8. Only 1% said they had 'complete control'. More than 65% of the respondents stated they were dissatisfied with the low level of perceived control, in both seasons (females tended to be more dissatisfied than males). The Pearson Correlation Coefficient between personal control over the environment and symptoms was slightly negative ($r = -0.12$; $P < 0.01$; $df = 875$). In other words, very loosely, it can be said that self-reports of health symptoms seemed to decrease with an increased amount of control over the thermal environment. When they were asked: *In general, how often do you exercise any of the following options to adjust the thermal environment at your workplace?*

- Open or close a window
- Open or close a door to the outside
- Open or close a door to an interior space
- Adjust a thermostat
- Adjust the drapes or blinds
- Turn a local space heater on or off
- Turn a local fan on or off.

Drapes was the most frequently cited local thermal environmental control, with less than 30% stating that

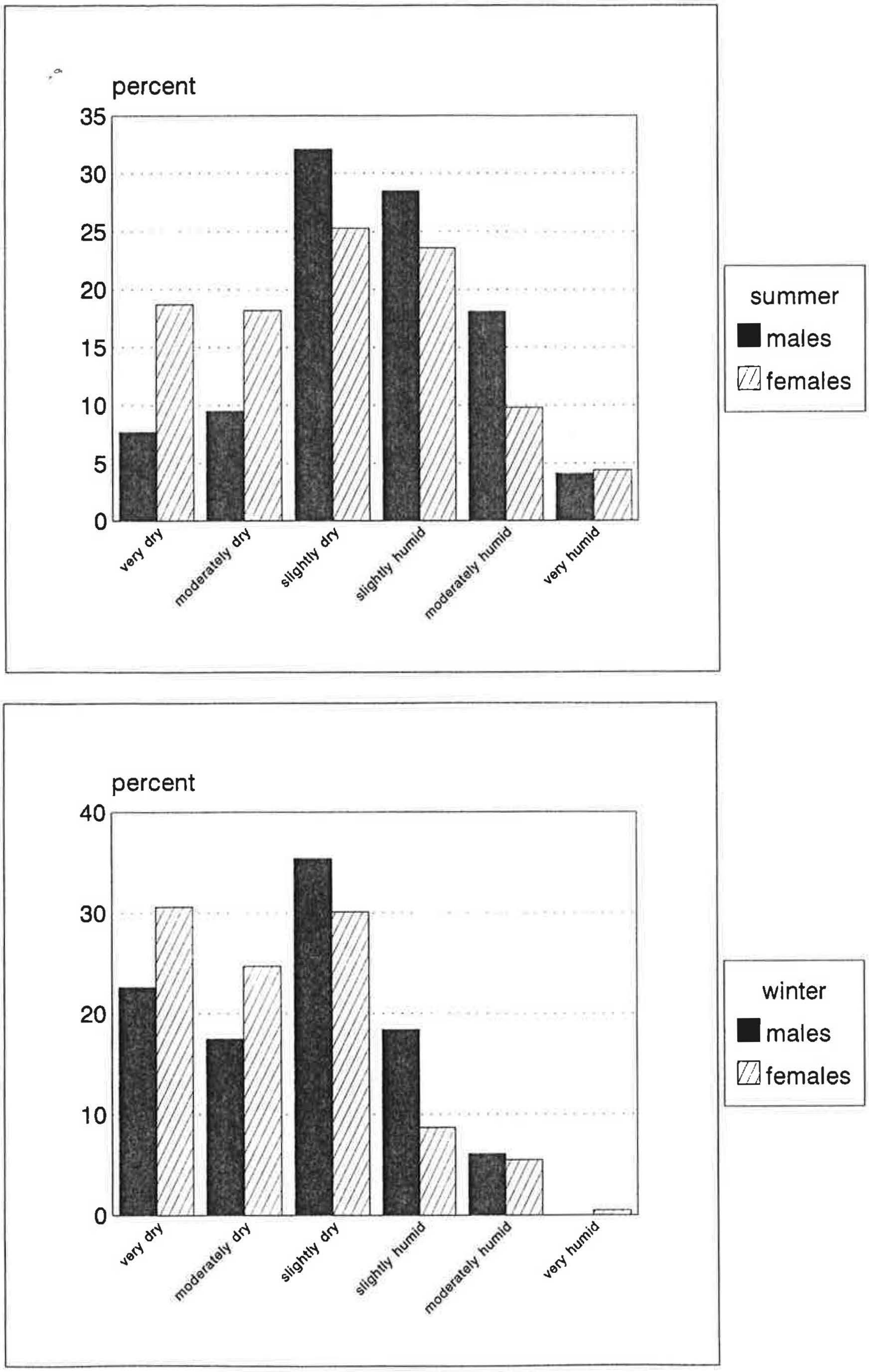


Fig. 6. Ratings of overall office humidity.

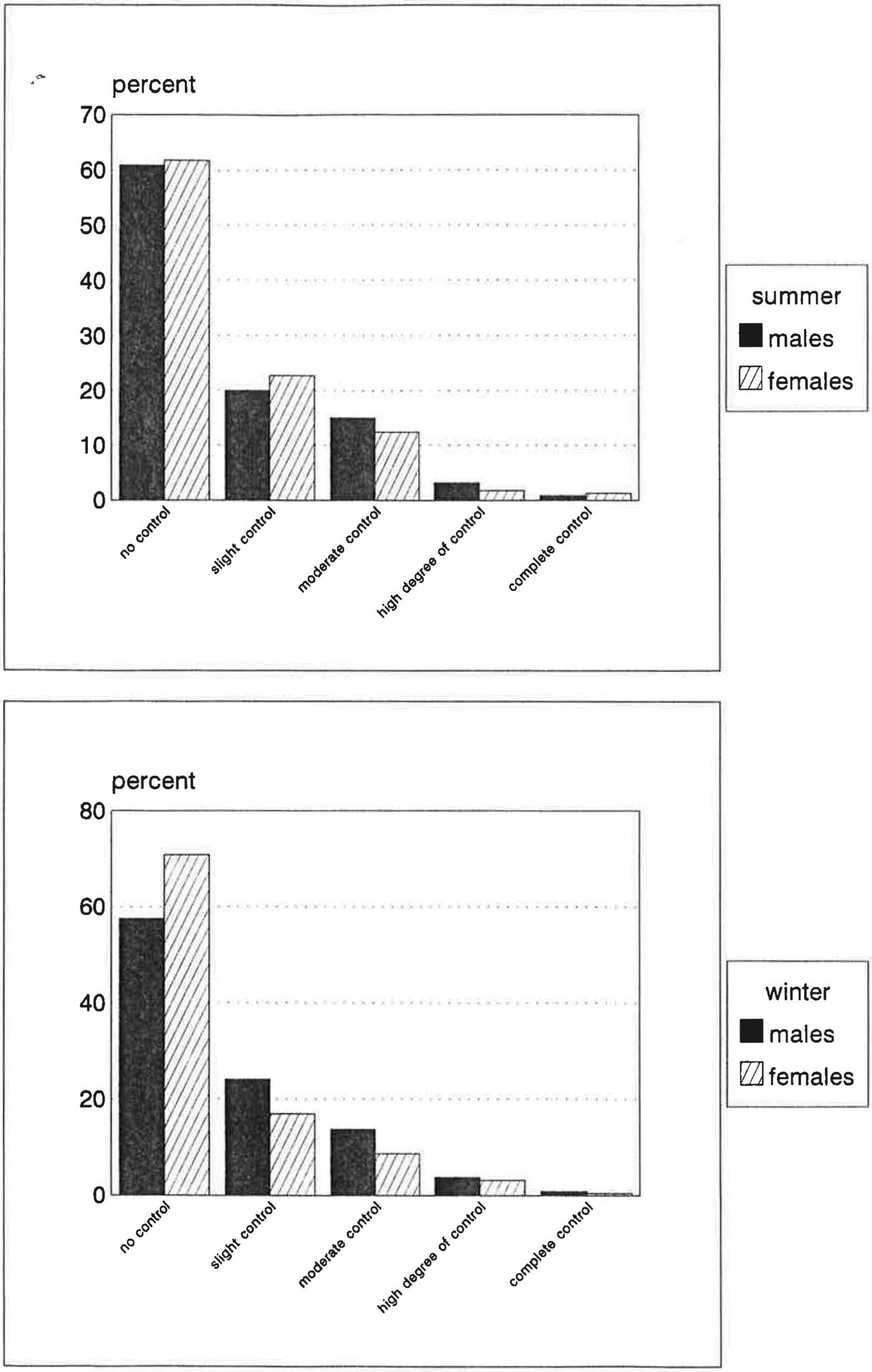


Fig. 7. Building occupants' level of control over thermal environments of their workstations.

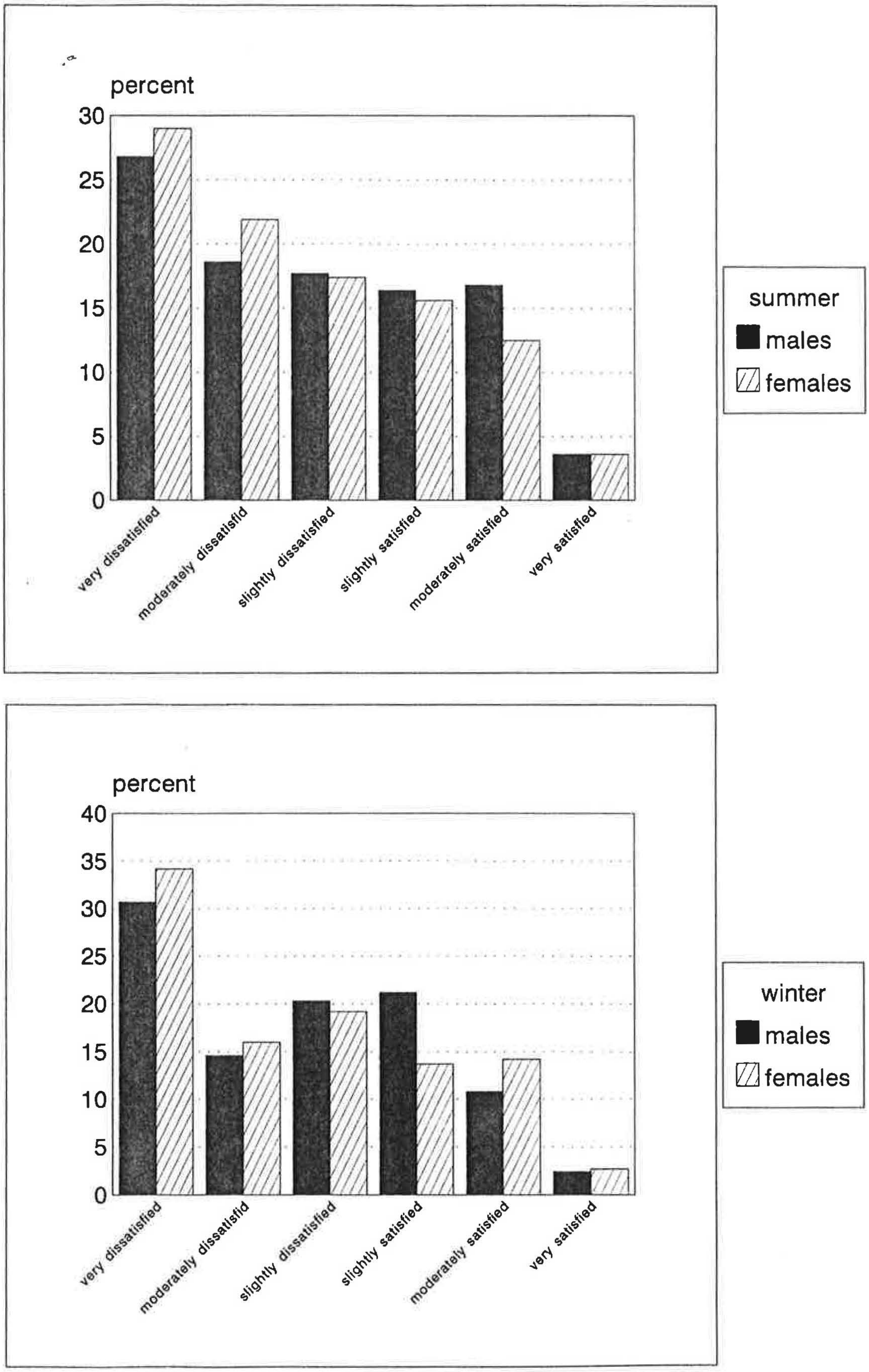


Fig. 8. Rating of satisfaction with the level of control over workstation thermal environments.

they were unavailable, Figs 9 and 10. However, over 18% claimed they never used the drapes, despite their availability. The next most frequently used personal thermal controls were internal doors and thermostats. The responses were almost identical in both seasons.

The degree of control that subjects perceived they had over their workstations's thermal environment was positively correlated with several factors: overall satisfaction ratings of work area temperature, air quality, ventilation and air circulation, perceived overall comfort, and acceptability. However, all correlations were moderate ($0.16 < r < 0.22$; $P < 0.0001$; $df = 875$). So, perceived levels of personal control seemed to have a small influence on office occupant evaluations of indoor climate.

4.4. *Overall environmental perceptions*

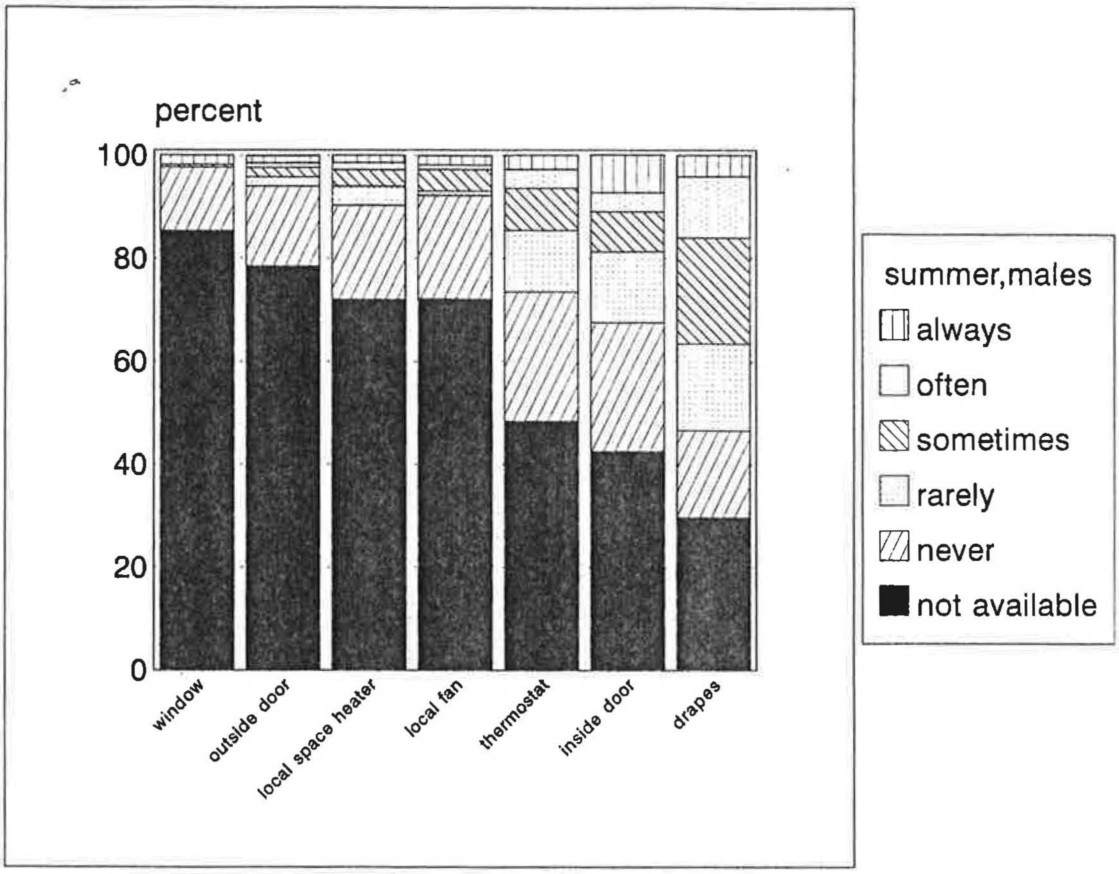
Respondents were asked to indicate their level of satisfaction with eleven aspects of their workstation environment. It was found, Figs 11 and 12, that the occupants most complained about ventilation, air quality, temperature, and privacy, in both seasons (the males were more dissatisfied with smoking areas than with temperature, during the winter/cold season). The most satisfactory aspects of the respondent's work environments were lighting, furniture, chairs, and colours, in both seasons. It was also found that the dissatisfaction rate increased by about 20% when the office space was of the open-plan type. The majority of the occupants rated their overall office acceptability as 'moderate'. The Pearson Correlation coefficient between the satisfaction of the overall comfort and the office's physical area (i.e., whether the office was in the centre of the floor or whether it was along the window-covered periphery) was nil ($r = -0.05$; $P < 0.01$; $df = 866$). However, the perceived overall comfort, and this only during the cold season, was slightly negative ($r = -0.11$; $P < 0.01$; $df = 428$). This indicates, though rather loosely, that occupants perceive themselves being more comfortable when along the periphery of the building. The majority of the respondents considered the lighting levels in their offices to be 'moderately' and 'very' bright. Less than 10% of the respondents rated the lighting levels to be 'dim'. The possibility that the visual environment inside buildings may interact with perceptions of the indoor climates was examined. Thermal sensation votes were correlated with the simultaneously measured lux value to yield a weak positive dependence ($r = 0.14$; $P < 0.0001$; $df = 874$). This, in fact, suggests that the total amount of lighting falling on the horizontal plane may have an effect on thermal sensation.

The satisfaction with non-smoking areas was analyzed against cigarettes smoked per day. The Pearson Correlation Coefficient between the two variables was moderately positive ($r = 0.25$; $P < 0.01$; $df = 865$). Those who did not smoke were very dissatisfied with the non-smoking areas, since there were none assigned. In all of the buildings tested, smoking was allowed in all spaces, however only 31% reported that they smoked. And those who did smoke were very satisfied with the non-smoking areas, since there were none—they could smoke everywhere.

4.5. *Other factors*

Ethnic differences in thermal response could not be examined in this study due to the extremely small numbers of non-Caucasian subjects, in the sample and population, respectively. The Pearson Correlation Coefficient between the health index and the number of caffeinated beverages consumed per day was almost nil ($r = -0.05$; $P < 0.01$; $df = 876$). Whether or not the worker drank coffee did not correlate with symptom reports. The Pearson Correlation Coefficient between the health index and the number of cigarettes smoked per day was almost nil ($r = 0.02$; $P < 0.01$; $df = 876$), assuming that the subjects did not under-report their smoking habits. Subjects were asked to indicate the number of hours per week they spent exercising. There was no statistically significant association between the amount of exercise and any environmental rating.

The job satisfaction was compared with general, overall assessments. The Pearson Correlation Coefficient between the job satisfaction index and the overall perception of work area comfort was practically nil ($r = 0.11$; $P < 0.001$; $df = 871$). The relationship was slightly more positive between job satisfaction and overall office work area acceptability ($r = 0.29$; $P < 0.0001$; $df = 867$). This suggests that there was a moderate tendency for overall acceptability assessments to improve as job satisfaction increased, Figs 13 and 14. Positive relationships were also observed between the job satisfaction and satisfaction with office air quality, ventilation, work area temperature, and ratings of work area movement. However, in all cases, the correlation coefficients were relatively weak ($r < 0.2$; $P < 0.003$). The correlation coefficient between the job satisfaction and air movement acceptability was relatively weak ($r = 0.12$; $P < 0.0002$; $df = 870$). The relationship between the job satisfaction and thermal sensation was almost nil. Therefore, job satisfaction appears to be related only to overall office work area acceptability. It is weakly related to generalized assessments of the overall quality of the physical environment, but not related to specific thermal environmental conditions occurring at the time of the interview. In general, the occupants were moderately satisfied with their job in both the summer/hot and winter/cold seasons. Chances for career advancement rated worst in all cases. Pay was rated second-worst in the summer/hot, while time pressures was rated second-worst in the winter/cold. Co-worker relations, interaction with co-workers, the job overall, and supervisor relations rated



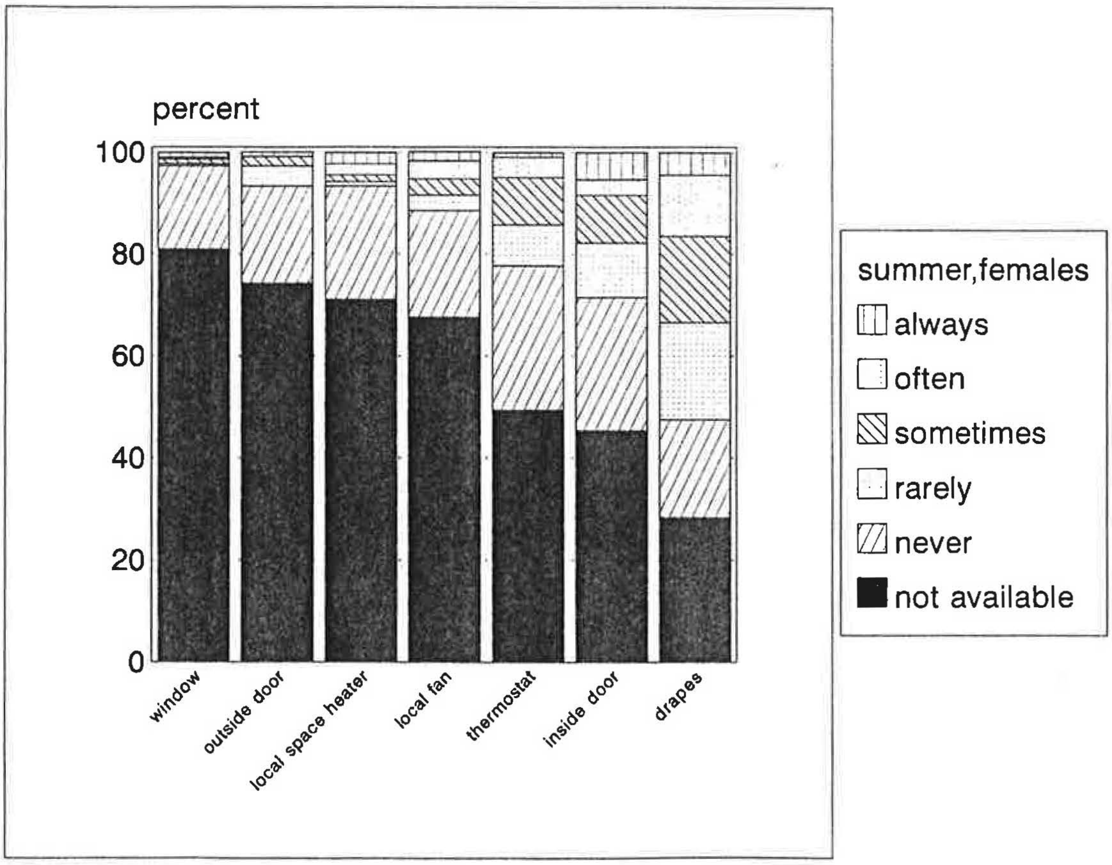
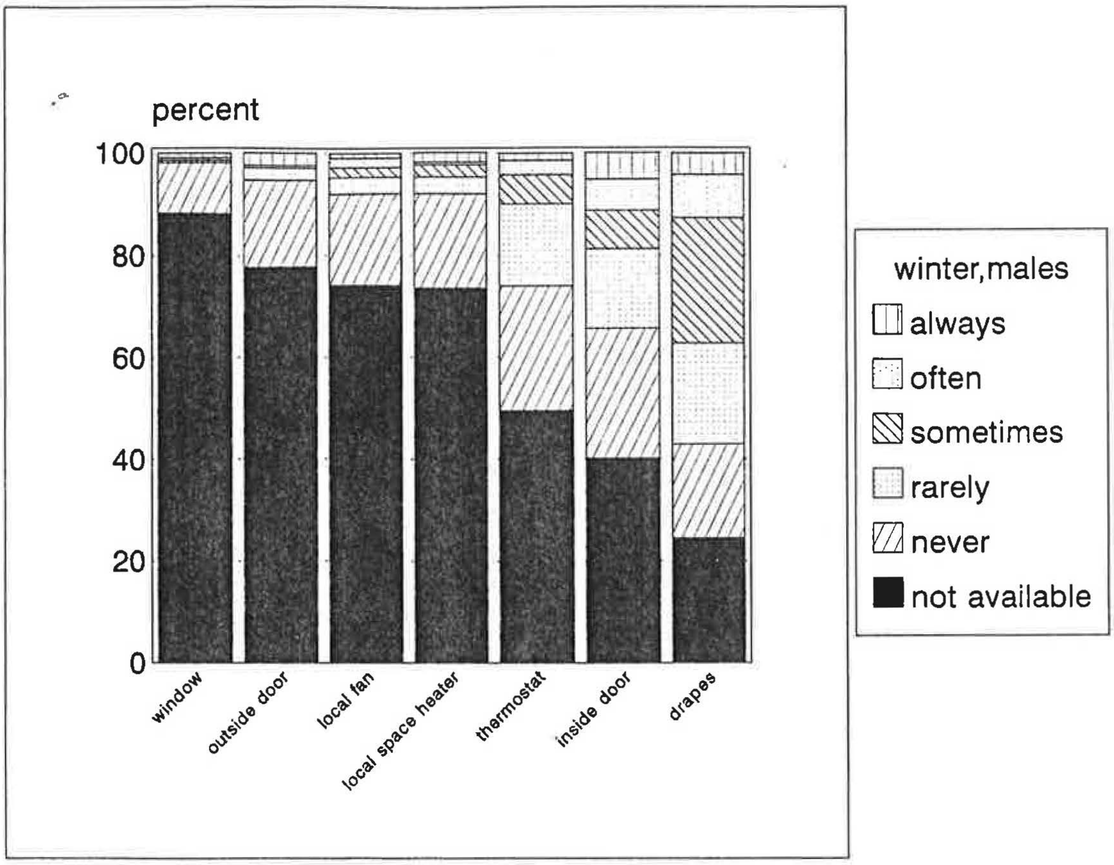


Fig. 9. Frequency of personal indoor climate control usage (summer season).



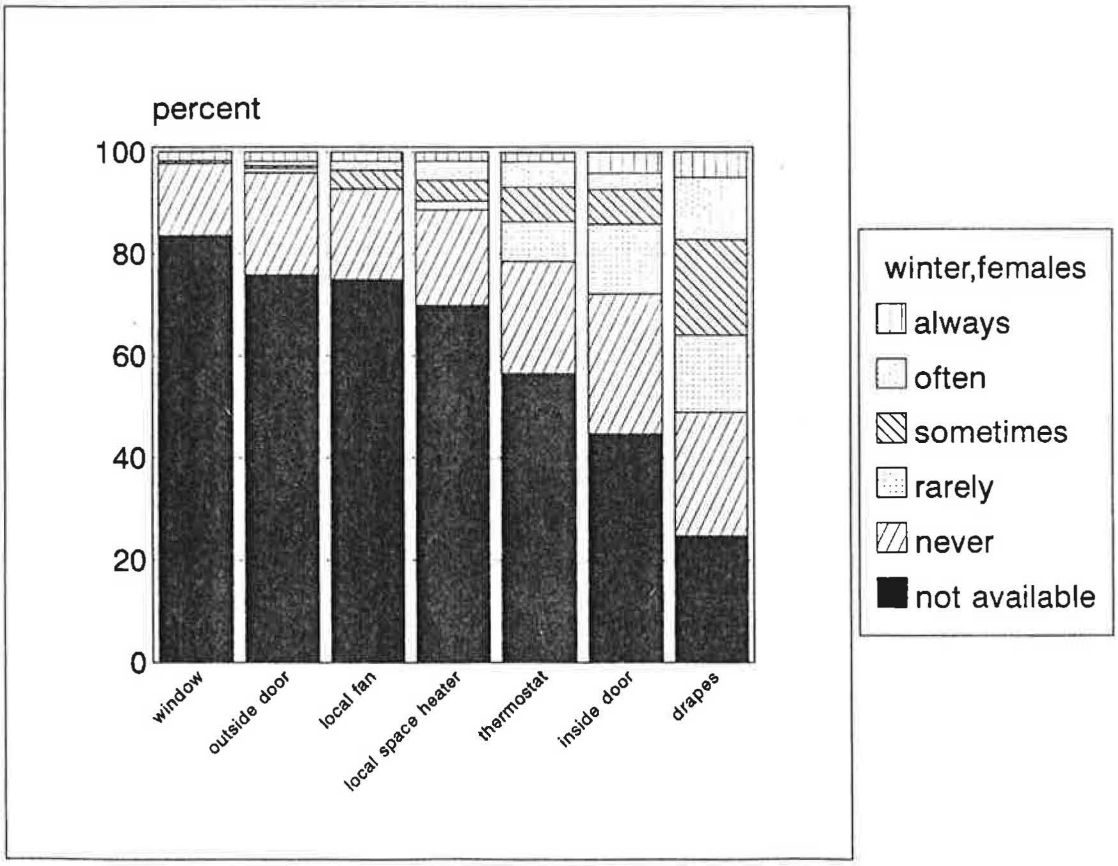
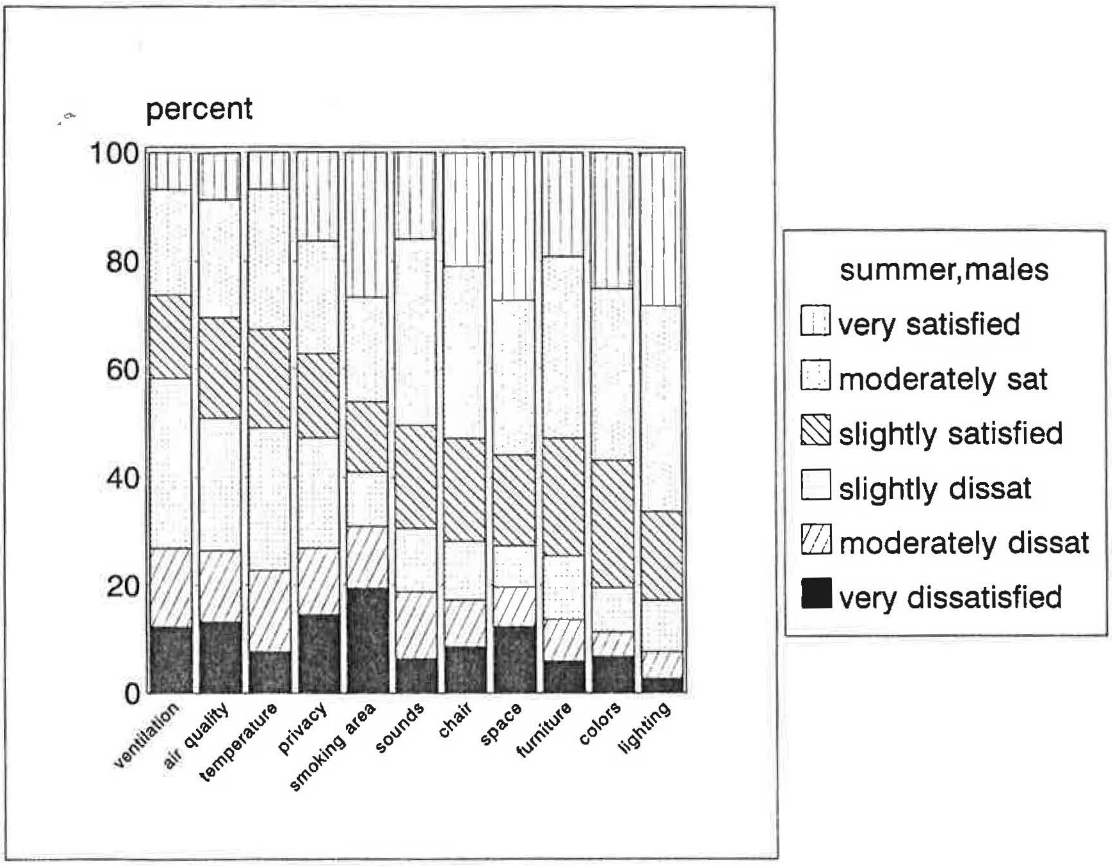


Fig. 10. Frequency of personal indoor climate control usage (winter season).



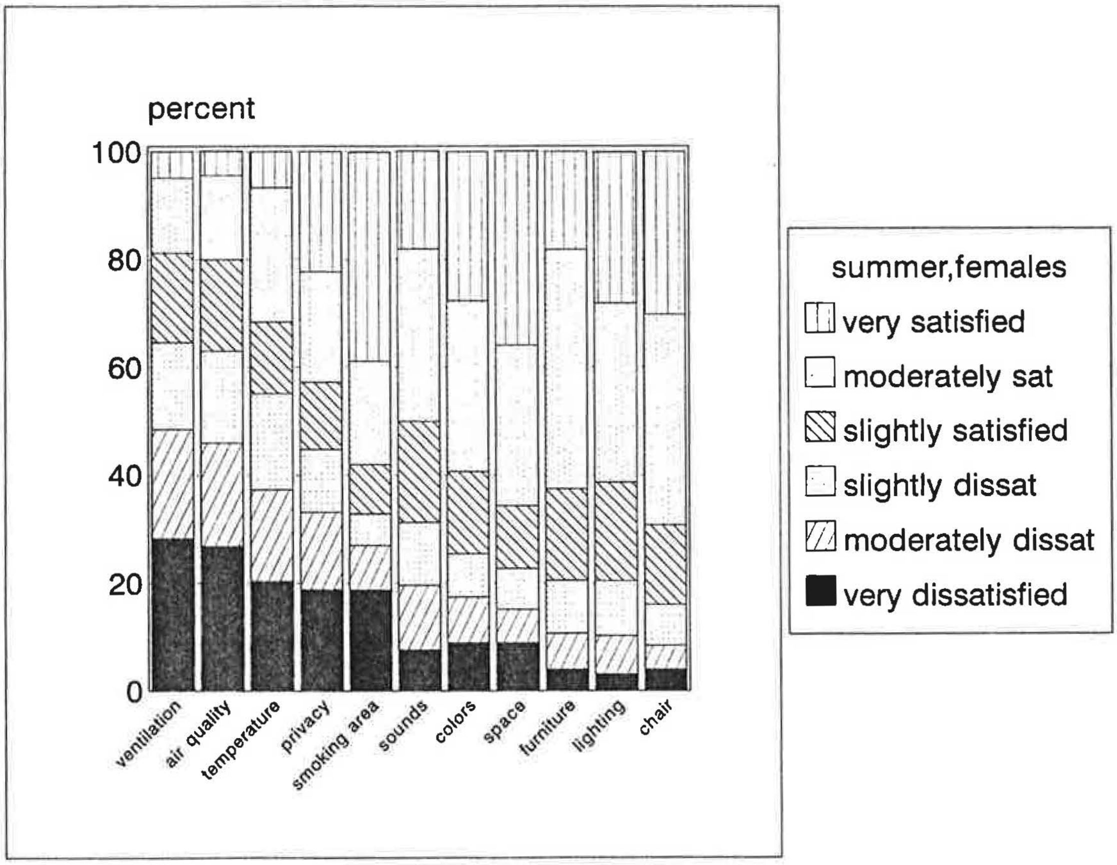


Fig. 11. Work area satisfaction ratings (summer season).

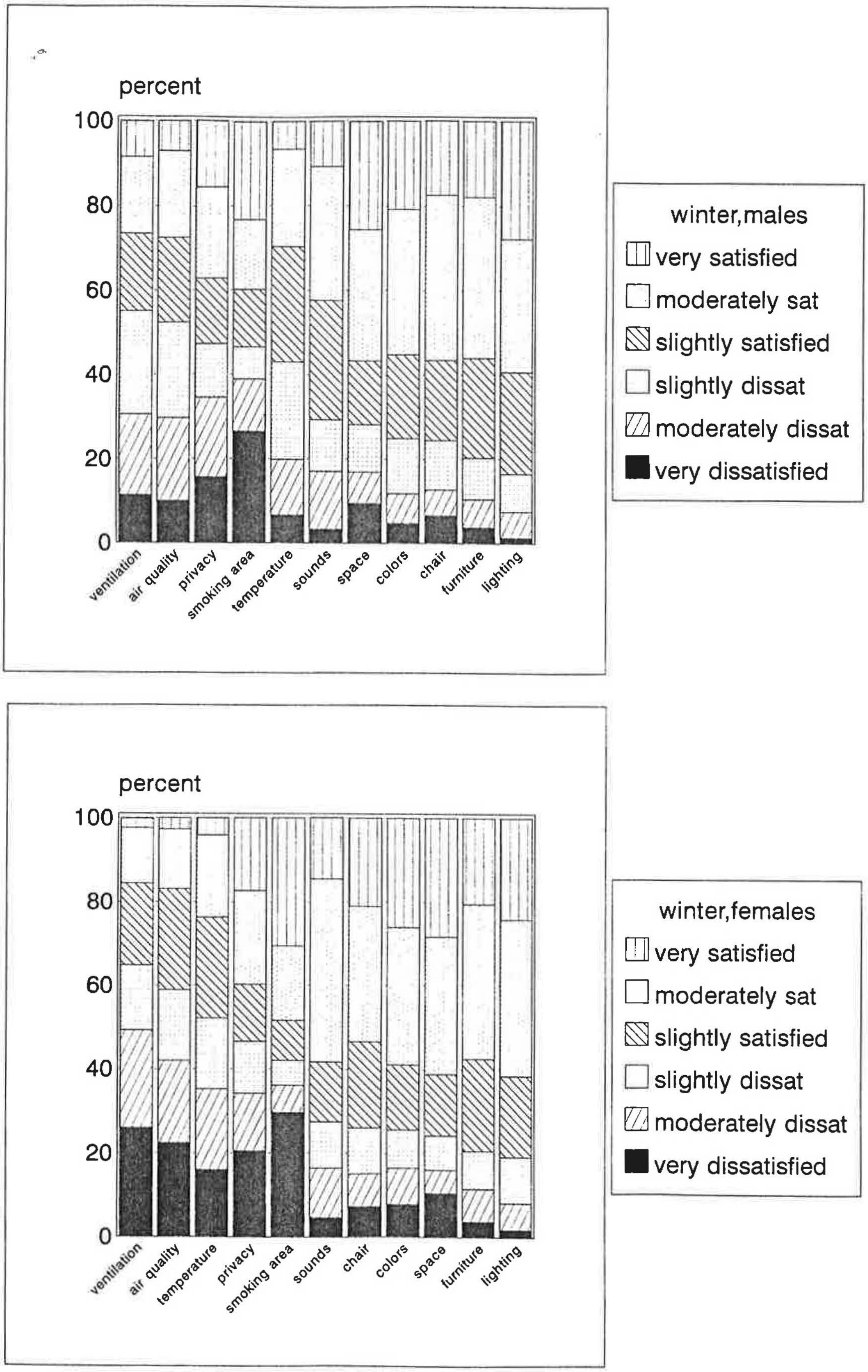


Fig. 12. Work area satisfaction ratings (winter season).

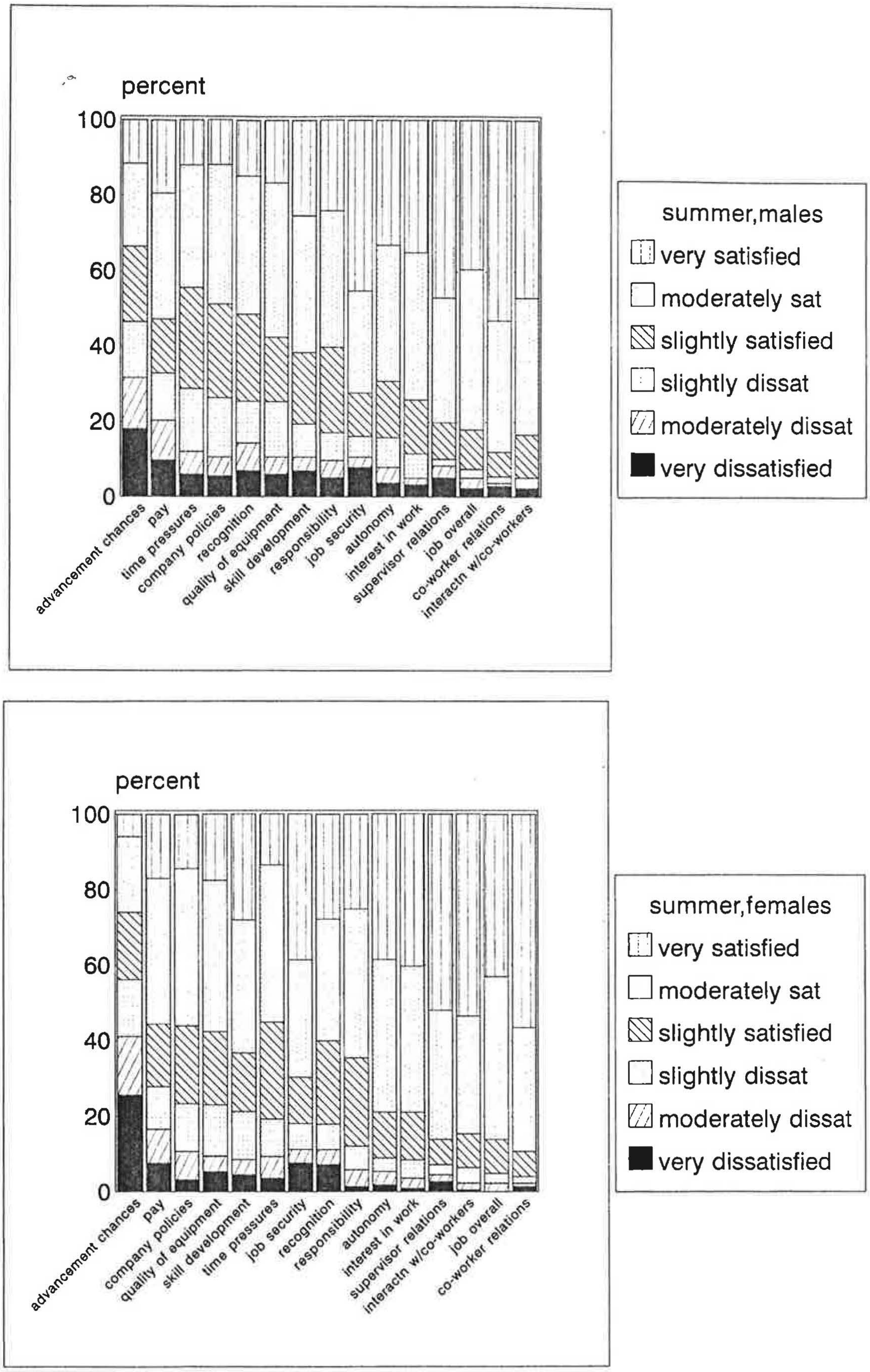


Fig. 13. Work satisfaction ratings (summer season).

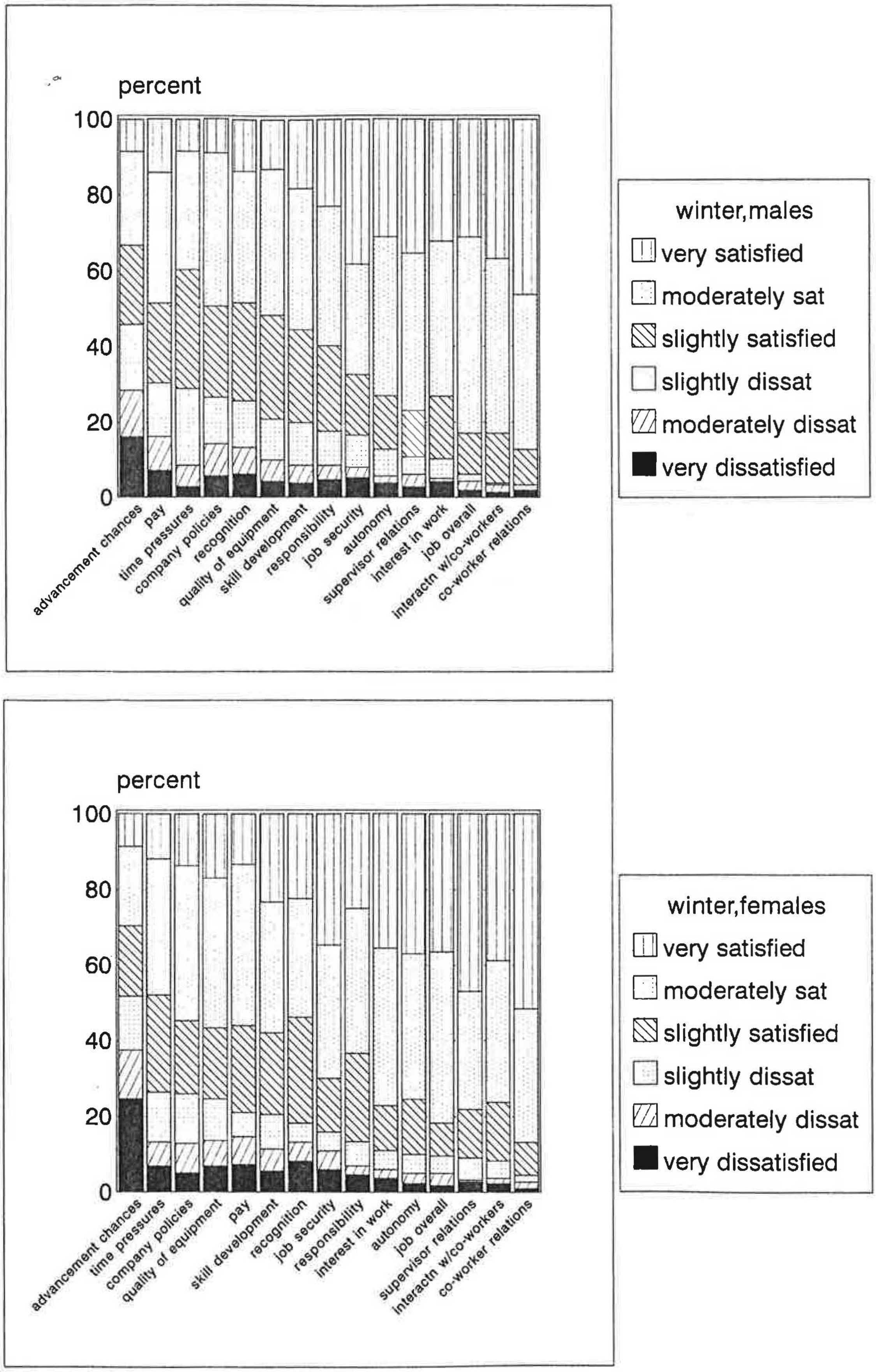


Fig. 14. Work satisfaction ratings (winter season).

the highest in all cases. It was found that job dissatisfaction did not correlate with symptom reports. The Pearson Correlation Coefficient between the job index and the health index was practically nil ($r = -0.08$; $P < 0.01$; $df = 871$). While job satisfaction was moderately and positively correlated with overall generalized assessments of the workplace physical environment, it is not possible to infer cause and effect from these data.

5. Conclusion

The measurements have shown that the current air quality and ventilation comfort standards were met for CO_2 and CO levels. The only discrepancies were the average outdoor air flow rate in one building; which was half that recommended by ASHRAE 62-89R. The formaldehyde and total volatile organic compounds levels are moderately higher than recommended comfort levels. However, more than 56% of the occupants rated dissatisfaction with the indoor air quality at their workstation, in both seasons. Only 63% of the indoor climatic observations fell within the ANSI/ASHRAE Standard 55-92 summer comfort zone; 27% in the winter. However, only 69% of those surveyed agreed with the ANSI/ASHRAE Standard 55-1992 comfort zone. More symptoms were reported by workers who perceived IAQ to be poor. The more dissatisfied with the IAQ was the occupant, the more often the occupant self-reported health symptoms. Positive relationships were observed between the job satisfaction and satisfaction with office air quality, ventilation, work area temperature, and ratings of work area environment. However, job dissatisfaction did not correlate with symptom reports. The occupants were more dissatisfied with IAQ when they preferred more air movement (i.e., they felt too little air movement), and they were more satisfied with the air quality when they wanted less air movement (i.e., they felt too much air movement). In other words, the higher the perceived air movement, the greater the satisfaction with IAQ.

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