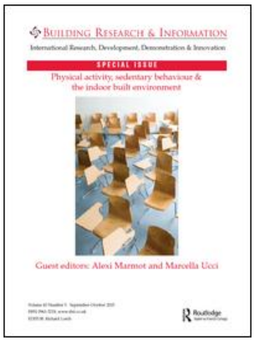

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A window of one's own: a public office post-occupancy evaluation

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ABSTRACT
The prevalence of mechanical climatization in office buildings, alongside the dictate to conserve energy, has misguidedly promoted the construction of buildings with non-operable windows. Research shows that such buildings are detrimental to their occupants' wellbeing and productivity, sometimes causing them to feel overcooled or overheated. This post-occupancy evaluation illustrates such problems through the case study of a courthouse building in a hot arid environment. A strong association is shown between occupant satisfaction, building ventilation and sense of wellbeing at work. A positive correlation was found between satisfaction with personal control, and overall satisfaction survey results show that workers express a willingness to compromise future salary rises in order to receive operable windows. Key lessons for architects are discussed.

KEYWORDS
architectural design; indoor environment quality; personal control; post-occupancy evaluation; sick building syndrome; ventilation; windows; workplace satisfaction

Introduction

Post-occupancy evaluation (POE) as a feedback for design: obvious yet ignored

Buildings are expensive. Yet, unlike other products (*e.g.* cars), they are rarely reassessed for adjustments and modifications. Thus, design mistakes are often repeated. Sporadic building re-evaluation and lack of standard procedures and protocols (Meir, Garb, Jiao, & Cicelsky, 2009) preclude systematic benchmarking of buildings, thus hindering sustainability (Roaf, Horsley, & Gupta, 2004).

The absence of regular feedback from performance to planning and construction phases is increasingly detrimental due to:

- a continuous rise in energy consumption per capita and in absolute terms (EIA, 2017)
- buildings in industrialized countries consuming 40–50% of the overall energy, from 'cradle to grave', but primarily for their operation (IEA, 2008)
- adverse environmental implications of the extraction and use of fossil fuels (World Bank, 2012)
- people in industrialized (but not only) countries spending 80–90% of their lives inside buildings, thus being affected by indoor conditions (Lan, Wargocki, & Lian, 2011; Lan, Wargocki, Wyon, & Lian, 2011; Wargocki, Wyon, Baik, Clausen, & Fanger, 1999); it is their 'natural human environment' (Meir et al., 2009)
- increasing demand for comfort in buildings coupled with the need to reduce energy consumption (Zeiler & Boxem, 2008; Zeiler, Savanovic, & Boxem, 2008)

The method providing feedback is POE, the systematic assessment of buildings once occupied (Bordass & Leaman, 2005). POE relies on plan analysis; monitoring of indoor environmental quality (IEQ) and thermal performance; and surveys, including observational walk-through, user-satisfaction questionnaires, semi-structured and structured interviews (Bordass & Leaman, 2004; Mahdavi & Proeglhoef, 2008; Roulet, Foradini, Cox, Maroni, & de Oliveira Fernandez, 2005; Zagreus, Huizenga, Arens, & Lehrer, 2004). However, the bigger the project and more complex the stakeholder relations, the more complicated POE can become (Davara, Meir, & Schwartz, 2006).

IEQ in the workplace

Buildings require increasingly complex support systems, such as a heating ventilation and air-conditioning (HVAC) system, yet their architectonic articulation is often simplistic, with fully glazed facades becoming the *bon ton* of contemporary architecture, especially that of

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office and public buildings (Salingaros, 2008a, 2008b). To lower energy consumption, users are usually given little control over their immediate environment: windows are often fixed, air temperature and ventilation are controlled by central systems, and lighting is standardized. Poor IEQ – and especially *perceived* poor IEQ – reduces workers' productivity in office buildings, and lowers student achievements in educational buildings (Kats, 2006; Leder, Newsham, Veitch, Mancini, & Charles, 2016; Mendel & Heath, 2005).

Improving IEQ, often just by enhancing ventilation and air supply, may yield annual economic benefits estimated between US$17 and US$26 billion for office buildings in the United States (Fisk, Balck, & Brunner, 2011; Seppanen, Fisk, & Lei, 2006), whereas a different aggregation of discomfort sources and their treatment has estimated potential productivity gains in the United States to be US$6–14 billion due to a reduction in respiratory illnesses; US$1–4 billion due to reduced allergies and asthma; US$10–30 billion due to reduced sick building syndrome (SBS) and building-related illness (BRI) symptoms; and US$20–160 billion due to improved worker performance from changes in thermal environment and lighting (Fisk, 2002). Even *perceived* control of one's immediate environment and IEQ parameters may have significant positive effects. These benefits are added to the higher return on investment (RoI) in green buildings (Gabay, Meir, Schwartz, & Werzberger, 2014). A major factor in IEQ improvement is individual control, especially access to operable windows (Ackerly & Brager, 2013; Brager, Paliaga, & de Dear, 2004).

Effects of control (windows, ventilation, cooling)

Windows are far more than apertures in walls. They determine the amount of natural light penetration, direct or diffuse, solar heating potential, the potential for comfort ventilation, structural cooling, provision of outdoor air and, not least, eye contact with the outside, significantly affecting wellbeing and productivity (Gilchrist, Brown, & Montarzino, 2015).

Studies indicate that workers with a view through a large window have faster response times than their peers with no view. Having a view-boosted performance, lessened fatigue and improved health (reported): 'An ample and pleasant view was consistently […] associated with better office worker performance' (Heschong Mahone Group, 2003, p. 138). Dilemmas such as daylight and view versus glare, solar heating versus overheating, or eye contact with the outdoors versus distraction can be solved or reduced through careful window design.

Ventilation is vital. Comfort ventilation widens the span of temperatures perceived as acceptable, thus delaying the operation of air-conditioning. In climates with wide diurnal temperature fluctuation, night ventilation allows structural cooling, which postpones the need to activate mechanical cooling the next day. This is achieved by turning the building's thermal mass into a heat sink. Slightly cooler temperatures than considered comfortable (setting the predicted mean vote limits in workplaces between −0.5 and 0) are even associated with performance improvement in workspaces (Lan, Wargocki, & Lian, 2011). Studies indicate a significant correlation between air flow rates and performance, connecting perceived rather than measured IEQ with diminishing performance, as ventilation rates decline from above 8 to 1 l/s per person (Myhrvold, Olsen, & Lauridsen, 1996), while outdoor air supply at increasing rates has been shown to increase performance by 1.7% for each twofold increase in ventilation rate (Wargocki, Wyon, & Sundell, 2000). Though providing such ventilation by mechanical means is common, operable windows seem an obvious alternative.

Operable windows

Under the title 'It's time to open the windows', Stych (2014) sums the advantages of operable windows. Defining control over one's immediate space as a basic human need concurs with several studies touching on measured and perceived IEQ, performance and satisfaction. For example, a late 1970s–early 1980s UK study of occupant window opening in 196 small offices situated in five naturally ventilated buildings showed that window opening occurred over the whole range of weather conditions. Windows had been opened in two modes: by a small amount to satisfy IEQ requirements; and to give large openings and higher rates of natural ventilation to control internal temperature. It was also observed that windows were opened during the operation of both heating and cooling systems in buildings (Warren & Parkins, 1984).

The literature shows that providing office workers with natural ventilation (*i.e.* operable windows) broadens the narrow temperature range of thermal comfort associated with artificially conditioned buildings (*e.g.* Nicol & Humphreys, 2002; Zhang, Arens, & Pasut, 2011). This, in turn, fosters energy conservation (provided controls prevent HVAC operation when windows are open). It also helps reduce SBS and BRI, both predictors of poorer performance, absenteeism and energy waste.

To avert SBS, buildings have to be studied after the user moves in. This paper illustrates problems, hindrances and actual effects through the case study of one complex building, part of the government campuses and courthouses in Israel, a large project undertaken by Israeli governments in the 1990s. The focus is on a specific building that could represent most of the other 225,000 m^2 of office space and 90,000 m^2 of courthouses in the country. The total area including parking and assorted spaces is over 450,000 m^2 (costing over US$700 million for the period 1993–2002; State of Israel, 2017). Soon after the buildings were occupied, rumours, complaints and protests by workers started spreading, based on claims of poor IEQ (Davara et al., 2006). Many complaints referred to lack of operable windows, and an open-space working area located in the core of the building with little or no access to the facade (Lior, 2001). Additional warnings were issued by the state comptroller (Davara et al., 2006).

These are the largest publicly initiated and operated projects in Israel. They house thousands of employees, and are visited daily by tens of thousands. A POE pilot programme was initiated to gain insight into the performance of the complexes through monitoring and analysis of energy and water bills; to evaluate anecdotal complaints; and to suggest modifications where necessary. As many of these buildings represent current practice in office building design, the pilot programme could yield guidelines relevant to the over 45% of the Israeli work force employed in office buildings. Originally meant for the Beer Sheva Government Campus, the pilot study took place in the adjacent courthouse building (Davara et al., 2006).

Case study

The new Beer Sheva stone-facade courthouse building is an imposing structure, even though its 50 metres are only half the height of more recent buildings in the city. It dominates the central business district (CBD) and the government campus area and serves the city's approximately 210,000 residents and the broader region's half a million residents.

Climate

Located on the Negev Desert lowlands (31.15°N, 34.48°E, 270 m above mean sea level, 45 km from the Mediterranean coast), Beer Sheva is characterized by a hot semi-arid climate, with wide temperature and humidity variability, diurnally and seasonally (BSh in Koeppen's climate classification). Summer days may reach over 35°C with 30% or even lower relative humidity (RH), while summer nights are much cooler, sometimes below 18°C, with RH of 80–90%. During hot spells, air temperature may rise above 38°C. Winters are cool to cold, with daytime average temperature maxima of 16°C and night minima of 6°C, though in January and February minima can be 2°C and less.

The yearly average precipitation is approximately 200 mm. Global radiation on a horizontal surface in June is approximately 7.4 kWh/m^2/day. Prevailing winds are from west to north (except for night winter winds blowing from the east), reaching average speeds of 8–10 m/s (Bitan & Rubin, 1991/94; Potchter & Itzhak-Ben-Shalom, 2013). As such, the local climate allows operating free-running buildings in winter, in parts of the transition periods and even in summer.

Building

The new courthouse building, designed by Barhana Architects, as part of the massive revamp project of the government campuses, houses the district, magistrates, youth, traffic, family affairs and small claims courts, and implementation office, covering 55,000 m^2 on 16 stories (part in eight double-height stories) above ground and four basement levels of parking, services, cells and detention rooms. These are distributed between four symmetrical wings, two on either side of a central core housing the entrances and foyer, staircases, corridors, elevators and a café/restaurant (Figure 1). The building houses 368 employees, including 51 judges, and hosts over 1500 visitors a day. Approximately 100 detainees are brought every morning for trial and kept in the basement floor till the day's proceedings.

Tools and methods

The evaluation project started with a preliminary analysis of the drawings; meetings and observational walkthroughs with the project manager; casual discussions with employees, including judges; and a study of absenteeism and sick leave records.

The first systematic study of the building (March–May) included plans and documentation analysis; building walkthrough focusing on problem detection and sporadic adjustments; and occupant questionnaires, including structured and semi-structured questions, covering 10% of the building staff (36 employees: 18 in open spaces, 18 in cellular offices, April 30, 2006, 10:30–14:00 hours). A second round of 49 questionnaires was carried out at the end of the monitoring period (July 30, 10:30–13:30 hours), in the same types of workspaces and occupations as the first round, bringing the overall number of interviewees to 85, or 23% of the building's permanent population. Questionnaires were administered by interviewers at the workstations.

Monitoring indoor air temperature, RH and light intensity was undertaken in several spaces (open office space, judges' chambers with different window orientations, windowless legal assistants' rooms located at the core of the building, court rooms, the open-space reception area with a southern window, and basement floor) in three sets of one week each, using Onset

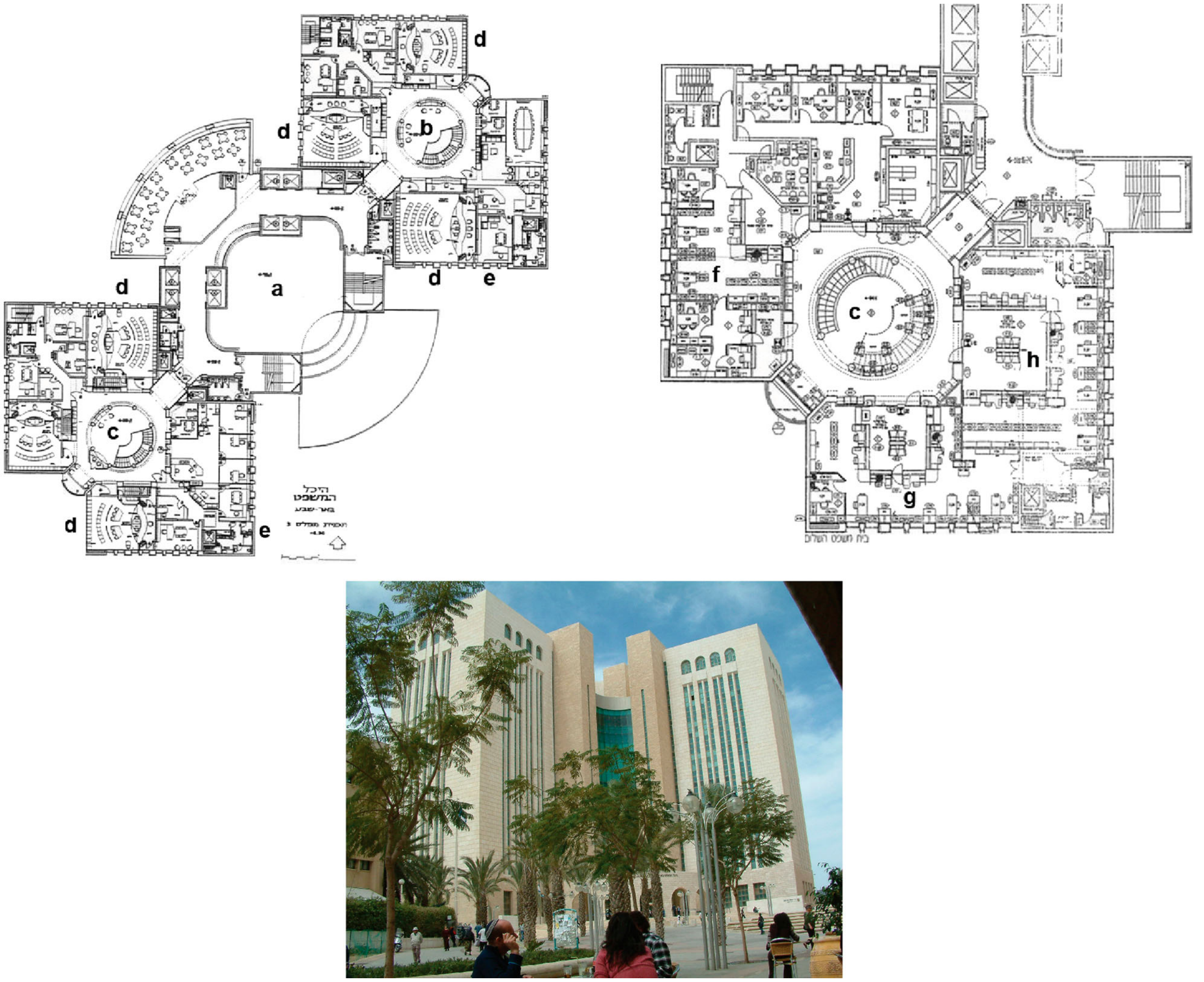

Figure 1. (top left) Plan of Be'er Sheva Courthouse: a, entrance; b, N wing; c, S wing; d, courtroom; and e, judges' chambers; (top right) enlarged plan of the S wing (c): f, small claims; g, criminal; and f, civil; and (bottom) view from the south-east.

HOBO data loggers with various sensors (air temperature, RH, light intensity, assorted external sensors). On-spot measurements were carried out at the workstations alongside interviews and questionnaires. For the measurements, we used a DELTA OHM HD8802 digital thermometer with a thermocouple K sensor (S110) and a Kurz 441-M-A-X air velocity meter; an MRC LM-8102 a handheld combined thermometer/anemometer/humidity meter/light meter/sound level meter. Questionnaires were adapted from Usable Buildings Trust (UBT) (2005) prototypes with modifications to the personal data. Monitoring and spot measurements were carried out at the workstations, at approximately 125–150 cm above floor level. Weather data were obtained from the Ben-Gurion University weather station, less than 2 km from the courthouse building.

The building's central HVAC system (variable volume, temperatures set at 20°C for winter, 25°C for summer) operated during working hours.

The research team looked at a measure of association between satisfaction with the working conditions and the number of SBS symptoms reported (see Figures 10 and 11), and calculated how the number of symptoms affects overall (dis)satisfaction. After preliminary results showed that symptom accumulation has dramatic effects, we decided to use that method of association as a relevant indicator.

Results and discussion

Long-term monitoring (March–May)

This took place in the spring (March–May), characterized in the northern Negev by comfortable temperatures during the day, but relatively cold nights. The average maximum daily temperature in Beer Sheva during the monitoring period was 23.5–26.3°C. The minimum average daily temperature was 9.8–13.5°C. North-western winds blow from noon throughout the afternoons, with dominant night and early morning eastern winds. Sets of (at least) one-week consecutive measurements were taken, covering both northern and southern wings (Figure 1), open spaces and cellular offices, different orientations of windows, windowless spaces and underground working areas.

Indoor air temperatures ranged between 21°C and 26°C during days, nights and weekends, with average temperatures around 24°C, while outdoor temperature fluctuated between 9.3°C at night to 31°C on some days. Judges' chambers have large operable windows, unlike other workspaces in the building, indicating the symbolic importance of windows in the occupants' hierarchy. The influence of the windows on indoor climate is illustrated by the following observations. In a west-facing chamber, relatively high indoor temperatures (24.8–26.7°C) were measured in the afternoon (16:00–18:00 hours). Owing to lack of proper external shading, complaints persisted, even with the internal blinds closed. In the south-facing chamber, indoor temperature ranged from 22°C in the mornings to 24°C in the afternoons. The lowest indoor temperatures were measured in a north-facing chamber: 21°C in the mornings, indicating limited solar penetration and the potential cooling effect of night northern winds.

In contrast, the following observations indicate that thermal comfort is sometimes affected by psychological factors. Legal assistants occupy windowless rooms, in the core of the building. Relatively constant indoor temperatures (around 24°C) were measured, regardless of time, weekday or weekend; except for mornings (08:30–09:00 hours), when temperatures were significantly higher (around 25.5°C), outdoor temperature ranged between 16°C and 19°C, well within the comfort zone (Nicol & Humphreys, 2002), while ventilation was constantly controlled by the central system settings, including the provision of outdoor air. Nevertheless, occupants complained of discomfort specifying SBS symptoms such as sleepiness, fatigue, headaches and dry skin, as well as lack of fresh air and bad ventilation, specifically lack of a window, indicating the psychological importance of windows in working spaces.

In the southern wing's open reception area, where a single operable window facing south was far from the workstation measured indoor temperature was 22–24°C during days, nights and weekends, with an average of 23.26°C. In spite of comfortable temperatures, the window was kept constantly open (reported and observed) on a par with complaints about heat and insufficient ventilation.

Indoor RH stayed low (usually 25–30%) in all measured spaces – with or without windows – regardless of outdoor humidity fluctuations. The eastern window chamber had a wider fluctuation between 19% and 45%, but the average RH remained low at 32.2%. The acceptable RH for indoor temperatures of 24–25°C ranges between 25% and 65% (Pearlmutter, Erell, Meir, Etzion, & Rofè, 2010, p. 22); however, insufficient humidity may cause SBS symptoms. Legal assistants complained of headaches, dry skin and sleepiness, disappearing upon leaving the building.

The criminal (south), civil (east) and small claims (west) departments and magistrates court (south-west) are on the second floor of the southern wing (Figure 1). They are typical of the court administration workspaces, housing around 200 workers. Arranged in a 'U'-shaped open-plan space, surrounding a central reception area, departments and windows are basically identical, except for facade orientation. A typical department has a single facade exposure, with a row of eight windows. Although originally designed as operable, those windows were not meant to be opened, since the building is fully air-conditioned. Workers' pressure led to the provision of handles, allowing the opening of windows. The handles became status symbols, usually kept in the drawers of department directors (see Figure 15).

Temperature in the south-facing criminal department was higher than the ambient temperature, quite pleasant in the spring (19–25°C during work hours). In the windowless spaces, both the cellular office and the open work area, temperatures often climbed up to 28°C and beyond, which is outside the thermal comfort zone.

In the open workspaces, temperatures were much lower, 20–24°C, perhaps due to the cooling effect of an open window in the night and early morning hours (observed). Air-conditioning was operated constantly in the open workspaces during work hours, regardless of windows' opening. On weekends (March 31–April 1, April 7–8), when the HVAC system was shut off, temperatures in windowless spaces dropped to 25°C and below.

No significant indoor temperatures differences were spotted in the civil and small claims departments between spaces with and without operable windows (Figure 2).

Ten employees of the civil department were among the questionnaire respondents. All complained about lack of temperature control and fresh air. The ability to open a window was mentioned as beneficial, but not enough to provide ventilation for the entire space.

Throughout monitoring, apart from a few exceptions, indoor temperature was always, during days, nights and weekends, much higher than outdoor temperatures, reaching 26–28°C, which is above the comfort zone.

The building's management offices are located on the upper basement level, alongside the main archive,

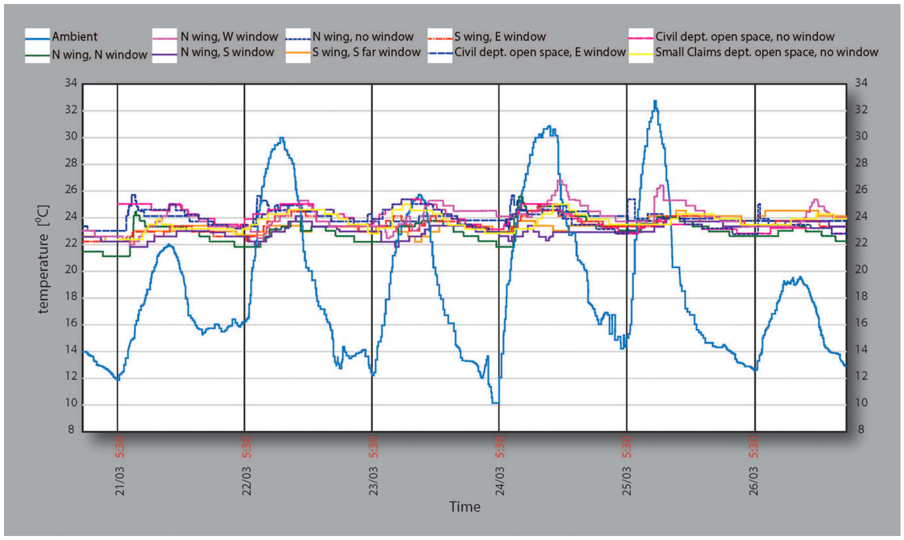

Figure 2. Monitoring of indoor temperatures in a typical week between March and May for different locations and orientations. 'Ambient' refers to outdoor temperature.

attached to a parking area. They have no access to 'fresh' outdoor air or natural light. The open-space reception area has an operable window, facing the underground parking lot. Occupants of these spaces complained about lack of a shaft to provide natural light and ventilation.

The reception area's temperature was, most of the time, slightly higher and less fluctuating than the manager's office. However, indoor temperature in all measured spaces had, again, no correlation with the outside temperature, and was usually between 21°C and 25°C, regardless of the day of the week.

Questionnaire analysis

Respondents' profile

A total of 85 questionnaires were filled in two sessions, covering roughly one-quarter of the building's routine tenant population. Most interviewees (63%) performed clerical work. The remaining 37% were distributed between legal assistants (11%), executive and management (8% each), security (6%) and judges (3%).

The respondents' age-group distribution is shown in Table 1.

Table 1. Respondents' age distribution.

Age group (years)	Share of respondents (%)
Under 25	8.3%
25–34	47.2%
35–44	13.9%
45–54	19.4%
55–64	5.6%
65 and above	5.6%

A total of 29 respondents (34%) work in a cellular office, while 56 (66%) share open workspaces. Most respondents (80%) were female.

SBS symptoms

The average number of symptoms was just over two, with the distribution shown in Figure 3. Most (149) symptoms were reported by 47 people who claimed relief upon exiting the building, while 32 were of 20 people who claimed no relief. Fatigue and headache were the dominant symptoms (Figure 4). Roughly two-thirds of the respondents reported fatigue during work hours, and almost half experienced headaches. Those two symptoms were responsible for over half the symptoms reported (54%).

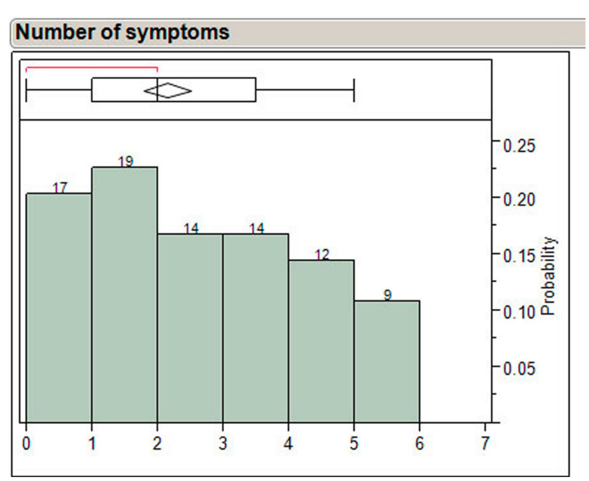

Figure 3. Distribution of the number of symptoms: *x*-axis, symptoms; and numbers on bars, the reported number of syndrome occurrences.

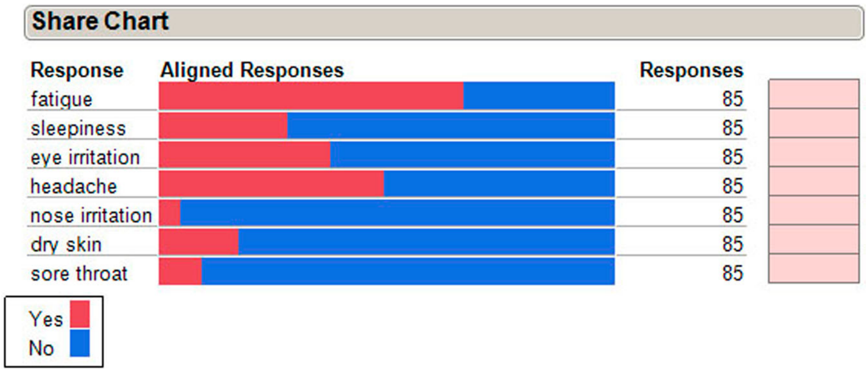

Figure 4. Frequency distribution of reported symptoms.

Satisfaction ranking

Respondents were asked to rank their satisfaction with parameters of the work environment, on a scale of 1–5 (1 = poor, 5 = excellent). The average score of each parameter is shown in Table 2. Satisfaction with ventilation is lowest, regardless of the presence of an operable window (2.88 with a window versus 2.7 without, compared, for example, with noise: 3.92 with a window versus 3.36 without; Table 2).

Satisfaction with personal control over the work environment is affected by the presence of operable windows (Figure 5). Surprisingly, no correlation was found between overall satisfaction with the building and presence of an operable window (Table 2 and Figure 5). These findings are discussed below.

Excluding odour, the average satisfaction with all parameters was higher among respondents with access to operable windows than among those without it (Figure 6). This agrees with POE studies, which

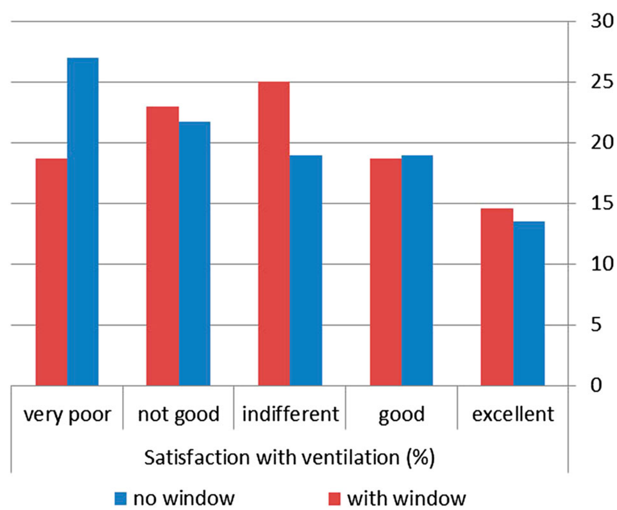

Figure 5. Ventilation satisfaction distribution by the presence of operable windows.

Table 2. Average satisfaction score of different physical attributes of the work environment.

Parameter	Average satisfaction score, total sample	Respondents with a window	Respondents without a window
Ventilation	2.80	2.88	2.70
Perceived temperature	3.36	3.48	3.22
Noise	3.67	3.92	3.36
Lighting	3.96	4.02	3.89
Privacy	3.51	3.50	3.51
Odours	3.37	3.19	3.61
Personal control	3.74	3.98	3.43
Overall satisfaction (perceived)	3.90	4.04	3.71
Overall satisfaction (calculated)	3.54	3.63	3.43

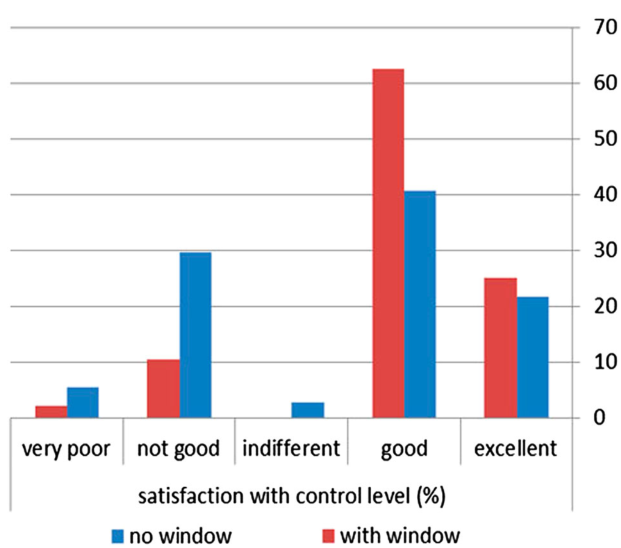

Figure 6. Satisfaction with personal control by the presence of operable windows.

found that occupants with some control over their work environment – mostly the ability to operate a window – are more tolerant of wider environmental conditions and forgiving of occasional discomforts (Deuble & de Dear, 2010; Leaman & Bordass, 2007).

Table 2 shows that overall satisfaction score (*i.e.* the average of all variables' satisfaction scores) is lower than perceived overall satisfaction. This is true for the entire sample, as well as for respondents with or without windows. Dividing the overall comfort score by the average of the variables yields the 'forgiveness factor', *i.e.* how people extend their comfort zone by overlooking environmental inadequacies (Leaman, Thomas, & Vandenberg, 2007). Here the difference between calculated and perceived satisfaction is wider in the case of tenants with operable windows, with a higher score for perceived satisfaction, indicating that personal control over one's workspace raises the 'forgiveness factor'.

Temperature

The average measured temperature in the surveyed areas at the time of the interviews was 24.5°C, similar to the findings of the long-term monitoring.

Maximum temperature of the on-spot measurements was 27.8°C, measured at the time of the second round of questionnaires, in an open-space workstation with western operable windows and centrally controlled HVAC. The occupant of this station ranked temperature, personal control and overall satisfaction as 'good', and noted the ability to control heating and cooling as a most important parameter.

Minimum temperature measured on-spot was 18.3°C, in an enclosed office, with individual air-conditioning and a southern operable window. The occupant was satisfied with temperature, ventilation, control level and generally with the building. However, he mentioned that temperature must be kept very low in the room, otherwise bad smells were released through the air-conditioner (perhaps due to poor filter and duct maintenance). The median on-spot measured temperature was 24.7°C.

No noticeable temperature differences were found between the two rounds, in spite of differences in outdoor temperatures: on April 30, between 11:00 and 14:00 hours, it ranged between 23.6°C and 27.1°C, while on July 30, for the same hours, it was between 30.2°C and 34.7°C. Air-conditioning operated constantly, regardless of whether windows were closed or open.

Average satisfaction with perceived indoor temperature was 3.36, second lowest after ventilation satisfaction. Respondents with access to an operable window ranked temperature satisfaction a little higher than those without

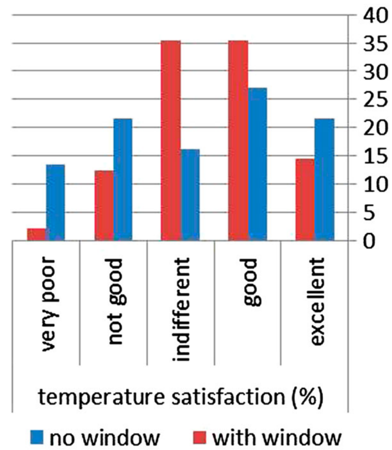

Figure 7. Average satisfaction with indoor temperature by the presence of operable windows.

such windows: 3.48 and 3.22 respectively (Figure 7), confirming the presence of the 'forgiveness factor'.

Lighting

Satisfaction with lighting level at the workstation was the highest parameter surveyed, regardless of the actual lighting level measured on-spot at surveyed areas, which ranged between 230 and 1500 lx (Figure 8).

The Israeli Institute for Safety and Hygiene recommends lighting levels of 500–750 lx in offices, based on the guidelines of the Commission Internationale de l'Eclairage (CIE).

No correlation was found between measured and perceived lighting level. All seven areas with a light intensity above 1000 lx are close to windows and their high lighting level may be due to the glare of the morning sun. Of these seven respondents, five ranked the lighting level as excellent or good, and one as not good, mentioning the too intense fluorescent lighting above her workstation. Another ranked the lighting level as very poor.

As a rule, the presence of a window corresponds to higher lighting satisfaction: above 4 (Table 2 and Figure 9). The striking discrepancy between the measured and perceived lighting level hints at a psychological explanation.

Noise

A considerable difference in noise satisfaction was found between respondents with operable windows and those without. While open widows may have been expected to generate complaints about outdoor noise, those with operable windows were more satisfied than those without (average scores of 3.92 and 3.36 respectively). These findings confirm other POE studies, suggesting that outdoor noise is not a problem for office occupants. Those dissatisfied

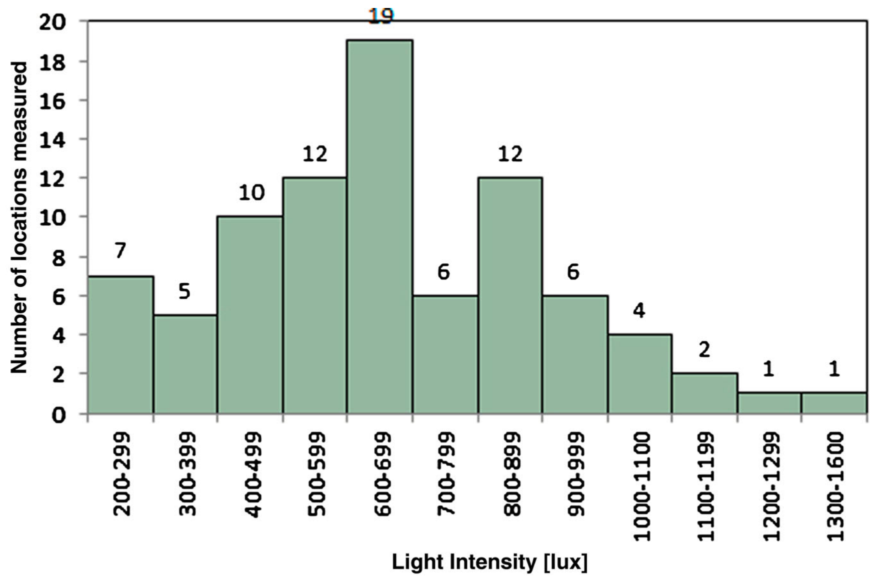

Figure 8. Lighting levels measured at surveyed areas.

with noise mentioned indoor noise 10 times more often than outdoor noise (Goins, Chun, & Zhang, 2012).

Satisfaction and what shapes it

As mentioned, the research team considered a measure of association between satisfaction with working conditions and the number of SBS symptoms reported (Figures 10 and 11).

Mean ventilation satisfaction on a scale of 1–5 was 2.8 ($n = 85$). Regression analysis showed that the number of symptoms is a significant predictor ($p < 0.0001$), accounting for about 30% of the variance in ventilation satisfaction ($R^2 = 0.296$). Mean satisfaction with degree of control was 3.7, much higher than with ventilation. Regression analysis showed that the number of symptoms is a significant predictor of control satisfaction ($p = 0.0003$, $r^2 = 0.148$), explaining 15% of the variance.

Mean overall satisfaction was 3.9, slightly higher than mean control satisfaction. The number of symptoms predicts 11% of the variance in overall satisfaction ($R^2 = 0.112$, $p = 0.002$).

As shown, the number of reported symptoms was most strongly related to reported satisfaction with ventilation (more, even, than to overall satisfaction).

Those reporting excellent or good ventilation satisfaction were 11 of the 17 symptom-free people in the entire sample (Figure 11).

Furthermore, ventilation satisfaction turned out to be the only predictor of both overall satisfaction and satisfaction with degree of control. Thus, 26% of the variance in overall satisfaction ($p < 0.0001$) is explained by ventilation satisfaction. Its relation to degree of control is nearly identical: $R^2 = 0.24$, $p < 0.0001$ (Figure 12).

The relation between three complaints regarding functional difficulties (typing, thinking and concentration) and ventilation satisfaction was examined using logistic regressions. These show that the reported difficulty in typing is unrelated to ventilation satisfaction ($\text{chi}^2 = 1.1$, prob. $> \text{chi}^2 = 0.29$); thinking, marginally related ($\text{chi}^2 = 3.3$, prob. $> \text{chi}^2 = 0.07$); and concentration, significantly related ($\text{chi}^2 = 9.2$, prob. $> \text{chi}^2 = 0.0024$, $n = 85$).

Thus, ventilation satisfaction seems a determinant of wellbeing and functional difficulties. What shapes ventilation satisfaction? The presence of an operable window turns out to have no effect on the number of symptoms, functional complaints (thinking, typing, concentration) as reported in questionnaires and interviews, and only marginally on overall satisfaction. However, an operable

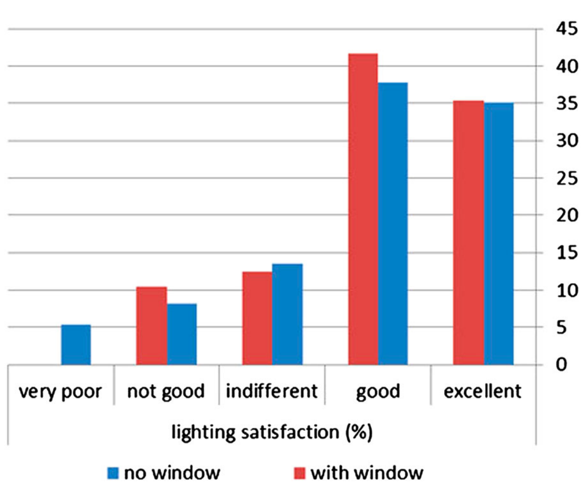

Figure 9. Lighting satisfaction level by the presence of operable windows.

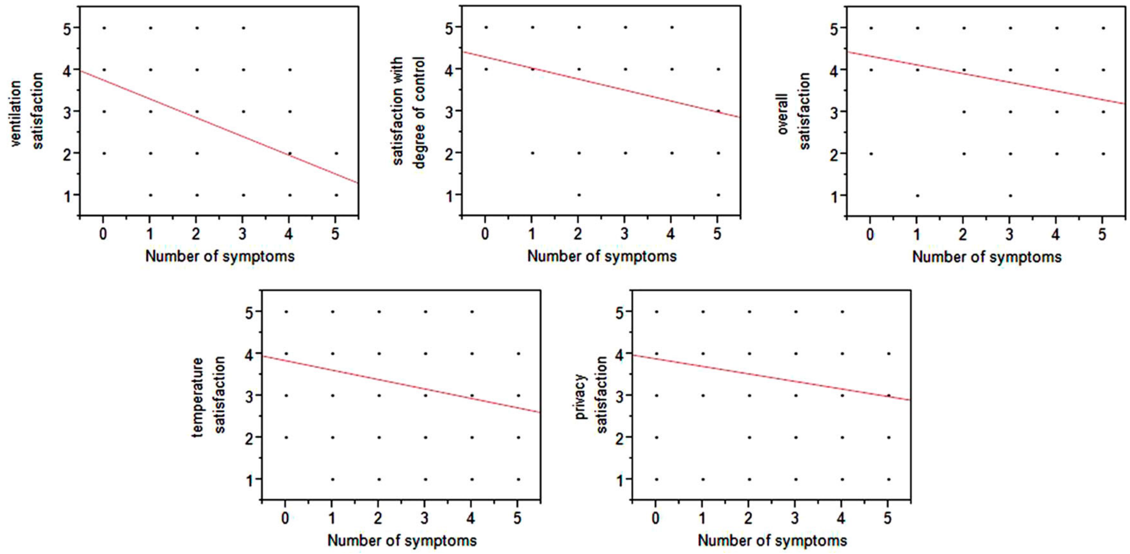

Figure 10. (left to right, upper row) Ventilation satisfaction by the number of symptoms reported; satisfaction with degree of personal control over the work environment by the number of symptoms reported; and overall satisfaction by the number of symptoms; (lower row) temperature satisfaction by the number of symptoms; and privacy satisfaction by the number of symptoms.

window did slightly improve satisfaction with degree of control.

Over two-thirds of the respondents were dissatisfied with the building's ventilation (ranking ventilation satisfaction fair to very poor), a surprisingly high rate for a new building, constructed under stringent standards.

Considering all respondent complaints about poor ventilation, sense of suffocation and lack of operable windows, ventilation dissatisfaction climbs to 74% of interviewees (63 respondents). While those without operable windows complained mostly of suffocation, lack of fresh air and natural light, respondents having operable windows complained of draughts, blowing their papers off the desk, as well as noise and smells entering from outside.

Apparently, the symmetrical design of building facades, regardless of wind or sun directions, combined with the windows' late adjustments led to dysfunctional windows (admitting solar radiation during the hot season and causing overheating, despite internal shades, being open, despite continuous air-conditioning *etc.*) and unsatisfied users.

A section manager in a private glass-walled enclosed office, without windows, complained of suffocation and was willing to remove the partitions separating her from her subordinates so as to enjoy the operable windows in the department's shared space.

Only eight of 37 windowless interviewees had no complaints about the building's ventilation. Two were security guards, stationed at the building's main entrance; another was a receptionist sat in the high-ceiling entrance hall, and the last was an assistant clerk whose work required them moving around the building. The nature of their work might eliminate the importance of operable windows. (Regarding the other four windowless interviewees, no unique characteristics were found.)

Ventilation satisfaction is essential to wellbeing, but we do not know what shapes it. It might be related to the degree to which people rank an operable window as important: the more important an operable window is to them, the less satisfied they are with the ventilation. However, the regression shows this relation to be insignificant ($r^2 = 0.07$, $p = 0.06$, $n = 49$). Most interviewees, regardless of ventilation satisfaction, rank an operable window as important (Figure 13).

The research team examined the relation between overall satisfaction and perceived importance of an operable window. A second-round sample analysis ($n = 48$) showed no correlation between the two. People with operable window indicated no relation between the importance they assigned to it and their overall satisfaction level (Figure 13, $r^2 = 0.02$, $p = 0.45$, $n = 29$). However, for those lacking an operable window, the more important it was to them, the less satisfied they were ($r^2 = 0.25$, $p = 0.03$, $n = 19$). Satisfaction with personal control and overall satisfaction with the building are strongly correlated. A total of 80% of respondents (68/85) ranked the two variables with the same score or one point difference. A regression showed that 9% of the variance in overall satisfaction ($r^2 = 0.089$, $p = 0.0064$, $n = 82$) is explained by satisfaction with personal control, *i.e.* operable window. In other words, having it makes it self-evident, but lacking it turns it into a vital necessity.

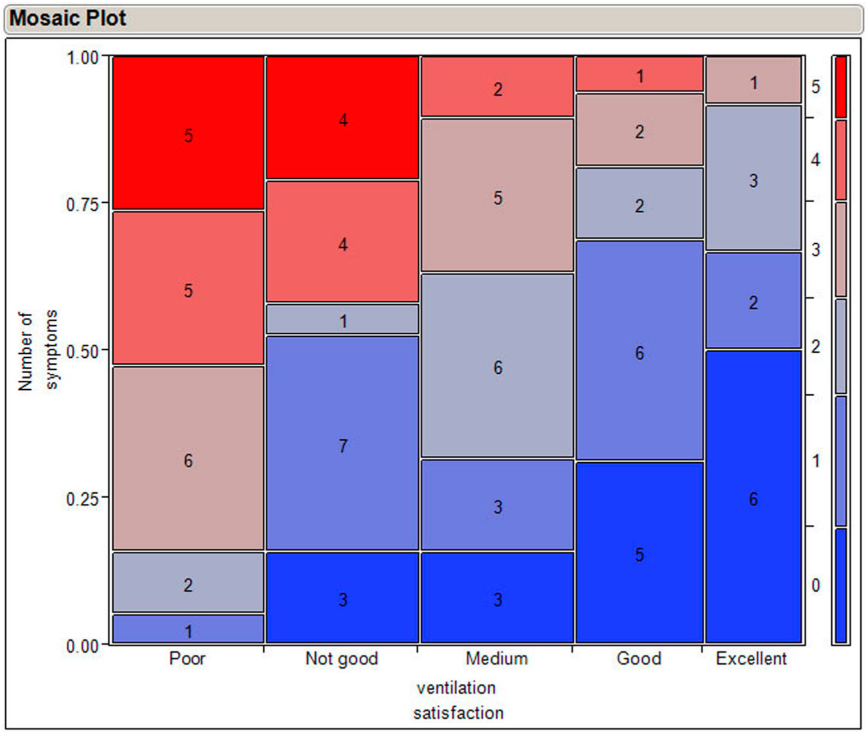

Figure 11. Ventilation satisfaction by the number of symptoms reported: mosaic plot. The width of each *x* category reflects the overall proportion of the answer in each. On the right, the legend represents the overall proportion of people with any given number of symptoms. The label in each tile shows the number of people in that category. The clear pattern is lessening symptoms as reported satisfaction with ventilation increases.

Second-round questionnaires

The second round of questionnaires took place three months after the first round, aiming to expand the database while assessing the importance of the work environment. It included three additional questions, focused on preference and the perceived importance of the parameters.

Interviewees were asked to rank the following seven workspace features (7 = most important, 1 = least important):

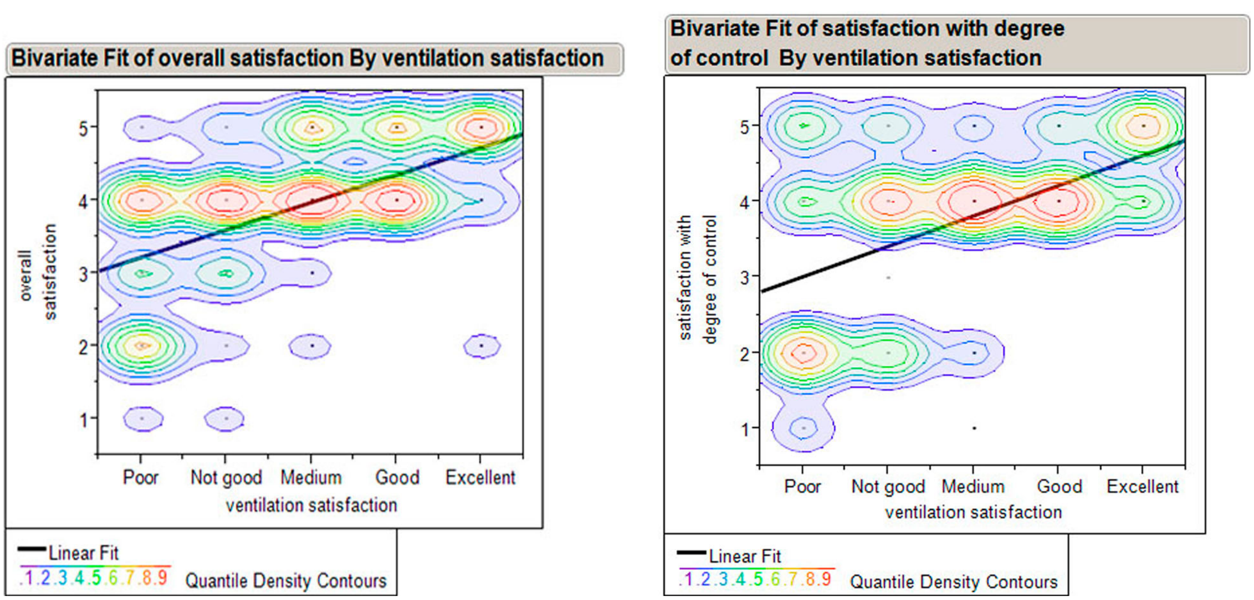

Figure 12. (left) Overall satisfaction by satisfaction with ventilation; and (right) satisfaction with the degree of control by ventilation satisfaction.

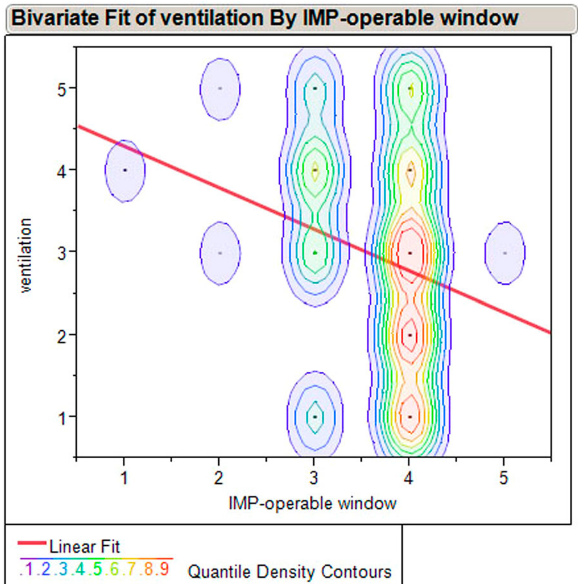

Figure 13. Ventilation satisfaction by the perceived importance of operable windows.

- personal control over heating and cooling
- natural light
- view
- parking space in the building
- room (versus open space)
- operable window
- accessibility during rush hours

The relative importance of the dimensions was assessed by scoring the number of times they appeared on top versus lower rankings, weighing each column, as shown:

"1st"="*15",
"2nd"="*10",
"3rd"="*5",
"4th"="*0",
"5th"="–*5",
"6th"="–*10",
"7th"="–*15",

(First*15 + Second*10 + Third*5 + Fourth*0 – Fifth*5 – Sixth*10 – Seventh*15).

Figure 14 shows that the most important parameters dealt with personal control of heating, cooling and operable windows. Natural light, indicating closeness to a window, was also important, while working in a cellular office was less important. Surprisingly, a view turned out to be the least important parameter. The overall scores from the survey ($n = 49$) follow.

Respondents were asked to rate those attributes. Parameters' average scores are shown in Table 3 (range 1–4, where 4 = very important, 1 = not important).

These results almost perfectly match the ranks derived from responses to the first question. In other words, the ranking assigned by individuals to these factors was invariant under different forms of questioning, indicating the robustness of the preferences.

In the second round, respondents were asked to rank their preferences for combinations of working conditions

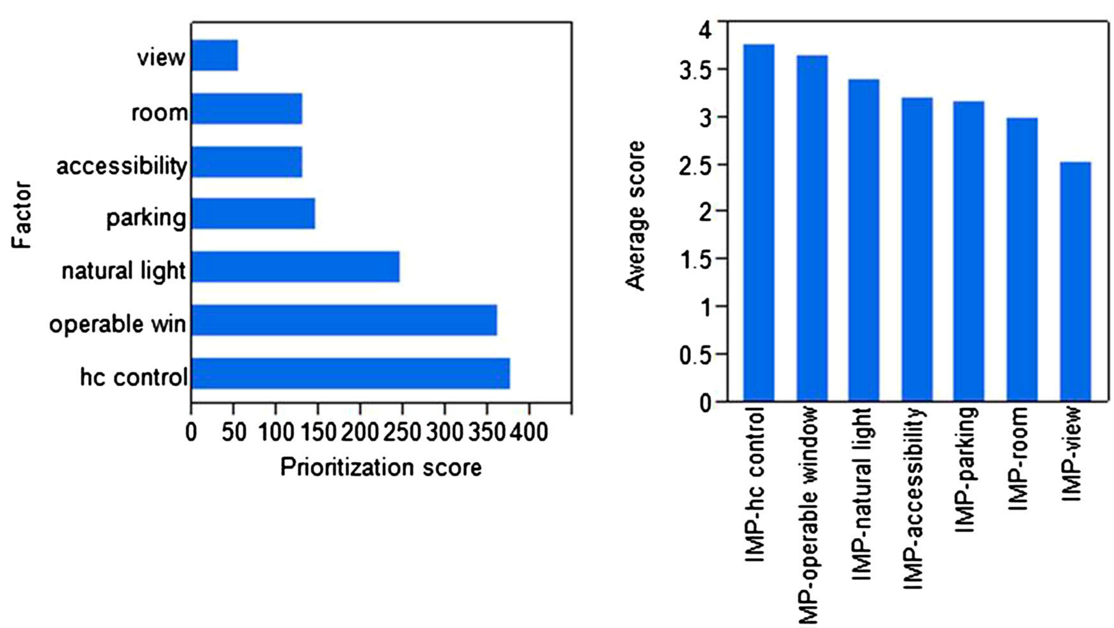

Figure 14. (left) Relative importance score (weighted) of work environment variables; and (right) average importance score of each independent variable.

Table 3. Parameters' average importance score.

Attribute	Average importance score
H/C control	3.77
Operable window	3.65
Natural light	3.40
Accessibility	3.20
Parking	3.16
Room (versus open space)	3.00
View	2.53

Note: H/C, Heating/Cooling.

Table 4. Average ranking of combinations of working conditions.

Combination	Average ranking
Fixed + 0	1.61
Fixed + 15	2.63
None + 30	2.00
Operable + 15	3.76

and salary (4 = most favoured, 1 = least favoured), as follows:

- no window at a workstation + 30% salary increase
- fixed window + 15% salary increase
- operable window + 15% salary increase
- fixed window + regular salary

The average score of each combination is shown in Table 4.

The combination of an operable window with a moderate salary increase was by far the preferred option. A total of 78% of interviewees (38) chose it as their first priority and 20% as their second. Of the latter, all but one chose the option of a 30% salary increment and no window as a preferred option. Surprisingly, a fixed window with a 15% salary increment was the second most favoured option.

A study of absenteeism and sick leave records indicated a rise in sick leave days per year per employee in the district and magistrates' courts in comparison with those in their previous accommodations (from 13.18 to 14.20 and from 11.12 to 12.30 days/year per employee respectively). The national sick leave average for Israeli salaried workers is 14.3 days/year per employee. This is in agreement with the SBS-related complaints and the expressed need for operable windows.

Conclusions

This study indicates a strong association between occupant satisfaction, building ventilation and sense of wellbeing at work. It was found that perceived insufficient ventilation is a predictor of SBS symptoms such as fatigue, sleepiness, headaches and concentration. Those satisfied with ventilation level are likely to be symptom free. Ventilation satisfaction was the best predictor of both overall satisfaction and satisfaction with personal control over the work environment.

Controlling heating and cooling and having an operable window, both forms of personal control, were most important for respondents. Natural light, a derivative of the presence of a window, is also important.

A positive correlation was found between satisfaction with personal control and overall satisfaction.

No correlation was found between overall satisfaction and the presence of an operable window. This finding contradicts those of other POE studies, which claim that occupants near operable windows are the most satisfied overall (Goins et al., 2012). This contradiction may be due to problematic functioning of the courthouse windows.

A robust correlation was shown, though, between overall satisfaction and perceived importance of operable windows, but only for windowless respondents. The findings suggest that lack of a window to those who consider it important reduces their sense of wellbeing.

Another indication of the perceived importance of operable windows is that more than 75% of the respondents expressed a preference for a window with a relatively minor salary increment over a considerable salary increase with no window.

Curiously, while theoretically the courthouse operates as a sealed building, most employees work near operable windows, as an outcome of workers' unrest after the building's first occupancy. This ad hoc adjustment led to air-conditioning operating with open windows, causing energy loss and raising operating costs. These drawbacks could have been prevented if architects had been aware of the importance of operable windows to occupants, which confirms the importance of post-occupancy feedback.

Over two-thirds of the sample were dissatisfied with the building's ventilation, a high percentage given the stringent requirements dictated by the customer (the government). In fact, average ventilation satisfaction score was considerably lower than any other parameter surveyed. Why does an operable window not improve satisfaction with ventilation? A possible explanation is the building's symmetrical design. Although both site and building layout are oriented with potential main facades facing north and south, which is ideal for an environmentally aware design, each of the building's two wings is designed symmetrically around a central core, and all building facades (and windows) are identical, regardless of orientation or the type of space they serve. No shading devices were provided for south-facing windows and no consideration was given to the protection of east- and west-facing windows from low morning and afternoon rays. Little consideration was given to wind direction, crucial in high-rise buildings with operable windows. Thus, high-velocity winds force occupants to close the windows, preventing them from enjoying the open-window effect. Indeed, complaints of draughts were repeated among respondents with operable windows, especially west-facing ones. These problems could have been prevented at the design stage by minimizing eastern and western exposure; applying vertical shading to western/eastern windows, external horizontal shading of south-facing windows, in addition to the existing internal venetian blinds; and even selecting a more radical approach, such as using a double-skin facade (see below).

While it is still common practice for high-rise office buildings to be designed as sealed and fully air-conditioned environments, a growing number of projects demonstrate sustainable solutions, meeting both the need to cut operational costs and occupants' desire for better personal control over the work environment (Shahzad, Brennan, Theodosopoulos, Hughes, & Kaiser Calautit, 2015). One effective solution is a 'double-skin' facade combining operable windows with a natural (or hybrid) ventilation strategy, generating air flow through the vertical channel created by it, providing fresh air into the indoor spaces, cooling the internal wall thermal mass. The external wall can be designed as a shading device and also improve acoustic insulation (Urban et al., 2016); thermal buffering and even insulation during summer and winter (Alberto, Ramos, & Almeida, 2017); energy savings and reduced environmental impact (Oesterle, Lieb, Lutz, & Heusler, 2001); transparency, natural light and visual contact with the outside; and, most importantly, natural ventilation, improving occupant comfort (Angeli & Dama, 2015; Lee, Selkowitz, Bazjanac, Inkarojrit, & Kohler, 2002). In high-rise buildings it can also help reduce the effects of wind pressure (Oesterle et al., 2001). In hot climates, it minimizes heat gains, helping to save energy and preserve occupant comfort.

Another natural ventilation solution is a fixed window with operable vents placed above and below it. The window provides natural light, while vents are occupant controlled.

The courthouse's indoor temperature is centrally controlled (except for a few enclosed rooms which have individual air-conditioners), ranging between 21°C and 26°C, with the average around 24°C, well within the comfort zone; however, the average temperature satisfaction score was 3.36, second lowest to ventilation satisfaction.

POE studies showed that the perceived comfort temperature is affected by personal control. Subjects having

Figure 15. Organizational hierarchy: removable window handle on a department director's desk.

more control over their workplace environment (especially operable windows) are more tolerant of conditions that are not in the centre of the comfort zone (Brager et al., 2004; de Dear & Brager, 2002). However, this study found no statistically significant relationship between temperature satisfaction and the presence of operable windows. Once again, occupants' dissatisfaction with malfunctioning windows and the corporate culture (directors monopolizing window handles; Figure 15) might disrupt the expected results.

Another important finding is the discrepancy between actual and perceived on-spot lighting level. Study findings show that while natural light is ranked high on importance, a view was the least important parameter.

Psychological parameters appear dominant in ranking comfort and preferences.

Limitations and implications

The specific building use, issues of privacy and data protection generated an unfortunate vagueness regarding the association of specific measurements or questionnaires with specific workstations, thus also with specific workers. It is vital that such information be coded appropriately, so that conclusions may be drawn regarding generic workstation types, but not specific ones. This, of course, creates a relative 'sterilization' of locality and personal attributes (*e.g.* specific worker, gender, preferences, location, existence/lack of operable window *etc.*). The use of monitoring equipment is also imperative, allowing the collection of the full range of relevant data. One appropriate strategy seems to be a preparatory meeting with the highest relevant authorities (in our specific case that would mean starting at the Ministry of Justice, including the security officer), to allow project briefing, demonstration of the equipment and its capabilities, and installation authorization. This complicates processes and adds potential bureaucratic barriers, but coordinating only with the local officers turned out to impact significantly on the research and its outcomes.

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