Workstation design for organizational productivity: practical advice based on scientific research findings for the design and management of open-plan offices

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Workstation Design for Organizational Productivity

Practical advice based on scientific research findings for the design and management of open-plan offices

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Overview

This guide provides practical advice on the design and management of open-plan offices to create an office that supports organizational productivity. All of the following office environment elements are addressed:

-Acoustics
-Indoor Air Quality and Thermal Comfort
-Lighting and Daylighting
-Workstation Design and Layout

The information in each section is based on objective, systematic research that examines the effects of office design on individuals and their organizations. The guide is primarily based on research completed by the National Research Council of Canada, Institute for Research in Construction (IRC/NRC), Indoor Environment Research and Public Works and Government Services Canada (PWGSC), Innovations and Solutions Directorate (ISD), as well as scientists with other leading organizations. Information about NRC and PWGSC and their projects can be found on their websites: http://www.nrc-cnrc.gc.ca and http://www.pwgsc.gc.ca.

The research used addresses many employee attitudes, behaviours and experiences, including satisfaction and comfort, health and well-being, task performance, absenteeism, and staff turnover. These reactions to office environments have all been considered and incorporated into the guide so that the recommendations benefit both the employee and the organization.

The guide deals primarily with open-plan offices because they remain the most common type of office space. However, alternative office strategies, such as hot-desks, team spaces and teleworking, are addressed briefly.

The symbol P.1 indicates additional resources and references available on the accompanying website: www.irc.nrc-cnrc.gc.ca/ie/productivity/index. To access these resources, simply click on the symbol in the electronic version of this guide.

Contents

Introduction

Taking a Look at Modern Office Design

Around 50% of North Americans work in offices, and a large percentage of these work in open-plan offices. Because people spend up to 90% of their time indoors, and much of it in their workplaces, the physical environment in offices should be carefully designed and managed. The physical conditions that occupants experience are important determinants of satisfaction, comfort, well-being, and effectiveness. P.1

Open-plan office

The term "open-plan office" refers to an office space divided into relatively small cubicles/workstations by partitions (also known as screens or panels) and modular furniture. The arrangement of workstations is flexible and the number of partitions per cubicle may vary from zero (bullpen-type) to four (cubicle). There are no full-height walls and doors separating occupants. The design was originally created to make better use of space and enhance the flow of information.

The Modern Work Environment

Changes in modern business practices have considerably changed the way we work in the office. Gone are the days of large areas filled with rows of clerks and typists conducting routine, repetitive tasks. When doing modern knowledge work, employees are required to analyse and integrate complex information, create new ideas, learn new skills continuously, and work in collaboration with colleagues. Advances in information technology also mean that most routine tasks, such as text typing and data entry, are now integrated into more complex, project-based work. From a wider, organizational perspective, rapidly changing markets mean that organizations need to be flexible, cost-effective, and innovative in all aspects of business to keep up with their competitors. The timely delivery of low-cost, high-quality,

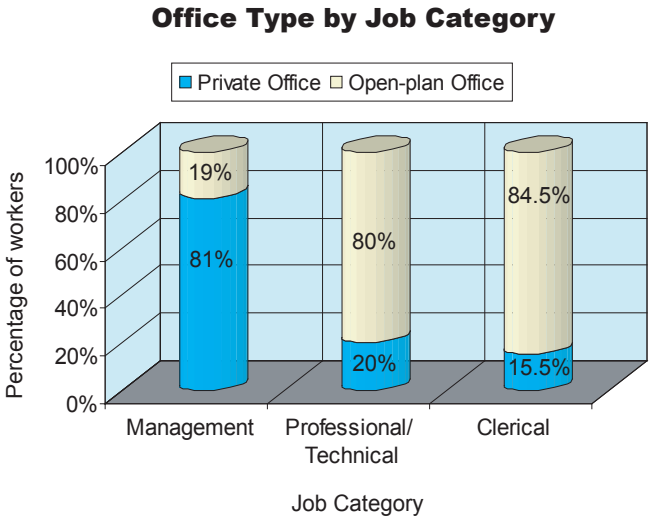
customized products and services to customers who are increasingly demanding is critical to organizational success.

These changes in business practices are being reflected in modern office designs.

New open-plan office, circa 2003.

Trends in Office Design

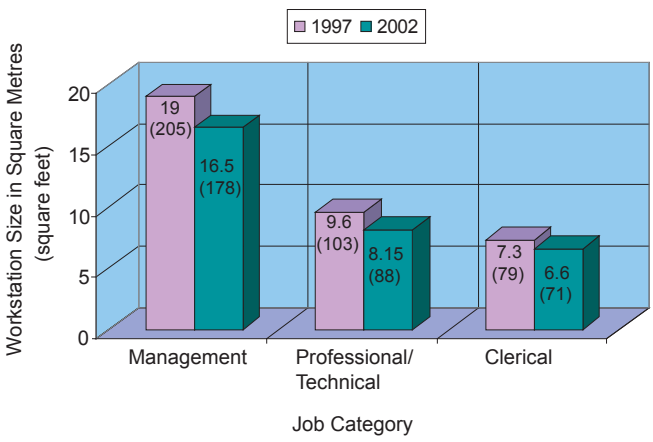
In an effort to reduce space costs and increase flexibility, organizations now make widespread use of open-plan offices in preference to enclosed offices. A recent survey by the International Facility Management Association (IFMA) found that 61% of North American office workers have open-plan offices. Brill and colleagues placed this estimate higher, at approximately 71%.



The majority of employees work in open-plan offices. Based on: International Facility Management Association (2002).

Over recent years, the size of open-plan workstations has decreased to further reduce real estate costs. IFMA estimated that office space per person decreased by 15% between 1997 and 2002. The organizational desire to increase communication and facilitate teamwork has also led to a

reduction in the height of partitions for open-plan office workstations.



In recent years, workstation size has dropped for all levels of workers. Based on: International Facility Management Association (2002).

Although open-plan offices remain the dominant office design, organizations experiment increasingly with alternative office designs. Office layouts that include team spaces, war rooms, and hot-desks are seen with greater frequency. Developments in information technology have also increased the flexibility of work hours and the possibility of telework. P.2

These trends lead one to consider the ways in which employees and organizational effectiveness are affected by the modern office environment.

Office Space and Organizational Productivity

Organizations typically see the physical office as a cost that needs to be minimized. However, poor or inappropriate design will result in poor environments, which create problems for occupants that may outweigh potential cost savings. For example, increasing office density can erode personal privacy, increase noisy disruptions, and reduce air quality. Office designs that reduce comfort and well-being, increase staff turnover and absenteeism, and make tasks harder to complete effectively will cost the organization more in the long run.

Designers, facilities managers, and organizations must think more broadly about the offices that they provide. Good design and operation will help to alleviate problems and ensure that modern office designs promote, rather than inhibit, organizational productivity.

Cost-effective Open-Plan Environments (COPE)

The principal source of information for this design guide was a recent 4-year consortium project, led by NRC's Institute for Research in Construction: Cost-effective Open-Plan Environments (COPE).

This project examined the effects of open-plan offices on occupant satisfaction. A multi-disciplinary team of researchers used literature reviews, simulations, experiments in mock-up offices, and field studies to determine how office design parameters (e.g. workstation size, ceiling type) affected physical office conditions (e.g. lighting, acoustics, indoor air quality), and occupant satisfaction.

The COPE products include a website, many research reports, and 2 downloadable programs that help assess open-plan office design. When using the software tools, users input workstation and office parameters and costs. The software calculates physical conditions (illumiance, noise level) and highlights features of the design that are positive or negative for occupants. The website and research reports are available at http://irc.nrc-cnrc.gc.ca/ie/cope/.

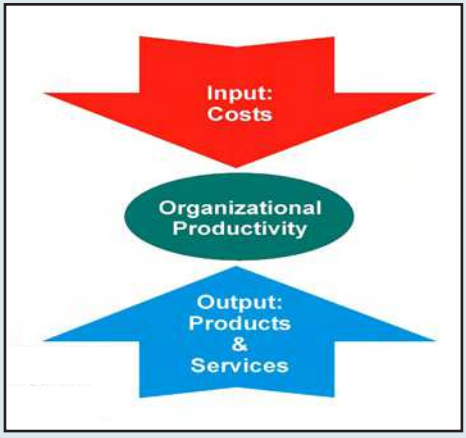
COPE-Office Design Evaluator (COPE-ODE) and COPE Calc, software evaluating the acoustic environment, are available at http://irc.nrc-cnrc.gc.ca/ie/cope/07.html.

The COPE project consortium members: NRC, Public Works and Government Services Canada, the Building Technology Transfer Forum, Ontario Realty Corporation, USG Corporation, British Columbia Buildings Corporation, Natural Resources Canada, and Steelcase Inc. These organizations helped fund and guide the research and continue to help channel research into practice.

Organizational Productivity and Office Design

"But what effect on productivity can I expect?" This question is commonly asked when improvements to the office environment are suggested. Business managers want to know that investing in office design will save money, cause employees to produce more, and improve organizational productivity. However, it is challenging to provide a realistic estimate of the effect on organizational productivity. That there is an effect is undeniable, and it begins to be identifiable when the connections between productivity, employees and office environments are examined.

What is Productivity?



An organization's productivity is the value of its output (the products and services it provides) relative to the value of its input (the costs incurred to run the business). The primary aim for an organization is to decrease its costs and increase its output so that it can be as profitable as possible.

Output - The Value of Products and Services: Often when people think about productivity, they consider only the output, and in particular the amount that individual workers produce. However, individual productivity is only part of the picture, and it can be difficult to measure what individuals produce. In the past, many office jobs were well-defined and repetitive, like those of data entry clerks or typists in typing pools. This made output from these jobs relatively easy to measure and compare – i.e. the number of forms processed, or the number of characters typed. Researchers can still measure single tasks like these, or they can study other office work components such as reading comprehension, text editing, summarizing text, or short-term memory. These skills and activities are useful indicators when studying employee behaviours. However, these performance measures no longer translate easily into productivity because their importance in different jobs varies widely. They represent only a portion of what modern

office workers do. Most office workers are now engaged in more complex knowledge work, the output of which is much more difficult to measure. They do not produce uniform units of output any more; nor do many perform single tasks repeatedly during a day. Rather their work consists of generating ideas and knowledge for a variety of different projects. These projects are typically novel and not easily comparable – does an architect's design for a house have the same value as a design for a shopping mall to the organization or the clients? What about an architect's product and a computer programmer's? In addition, modern office work is often conducted in groups or teams, which makes it difficult to determine the contribution from any specific individual.

Output can more easily be measured at an aggregate level. Most organizations keep financial records on sales revenue, business volume, market share and so on. However, other organizational output variables are hard to measure in dollar terms. For example, what is the value of fulfilling the public's expectation of a public service? Or the value of satisfying customers? These outcomes are important to the organization but are not easily quantifiable. Without quantifying these and other output measures, analysts find it very difficult to identify the effectiveness of any strategy, such as innovative office design.

Input - The Cost of Work: A complete picture of productivity must consider not only the output of an organization, but must also include the costs incurred to produce the products and services. For an organization to function, its employees need somewhere to work, the appropriate resources, materials, and support, a salary, training, and so on. Organizational productivity is the balance of all these costs, against the value of all the products and services.

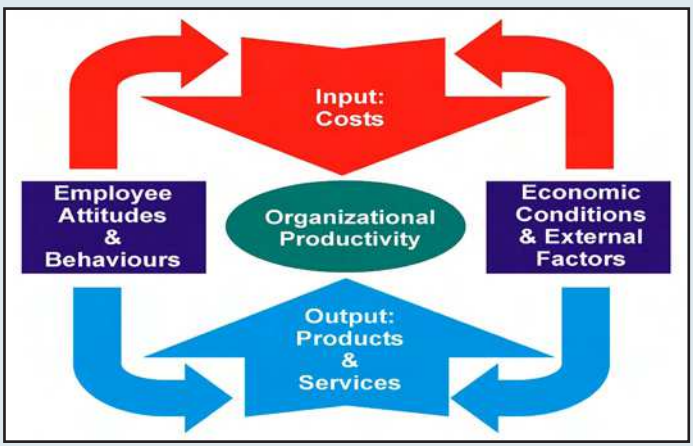
Many of an organization's costs are relatively straightforward to measure. For example, the amount spent on salaries or materials and supplies can be calculated. However, some costs consist of many elements and are difficult to estimate realistically. Recruitment costs include resources for advertising the position; time spent by human resources and other staff to develop the position description, handle resumés, arrange and conduct interviews, and make follow-up background checks; and the time and resources needed to make an offer and arrange personnel and payroll files, computer, e-mail and phone access, and orientation and training for the new employee. If recruitment is needed because an employee has left the organization, then the costs of an exit interview, the lost work from the unfilled position, the disruption to other employees in the department, the lost knowledge, expertise and contacts, and other associated costs also need to be factored into the equation. This equation has obviously become very complex.

Quantifying Productivity: Overall, although we can measure some of the input and output variables that contribute to productivity, it is very difficult to accurately determine all of the important contributors, and almost impossible to combine them into one financial figure representing productivity. One solution for individual organizations is to choose the input and output variables that are most important to them, and develop meaningful, context-specific methods of measuring them. In this way, an organization can track its performance against its own goals to determine its effectiveness. However, if we want a more generalizable way to examine productivity and recommend measures that will contribute to better success, we need to take a different approach.

A Different Approach

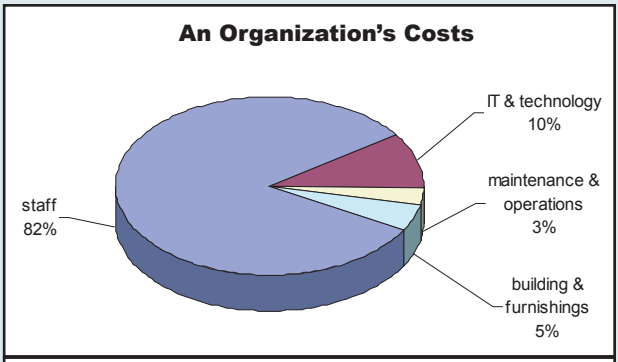
It is more useful to take a wider view of the factors influencing organizational productivity. There are two main influences on the input and output for an organization: economic conditions and external factors, and employee attitudes and behaviours.

Economic conditions and external factors are outside forces, like the labour market, the cost of supplies, and the market price for products and services. While these factors have a major influence, they are largely uncontrollable, and, therefore, cannot be manipulated for better productivity.



Employees, on the other hand, are greatly influenced by their organization's choices. They produce the goods and services that will be sold and are usually an organization's greatest asset. Employees are also the largest cost. Expenditures such as salaries, benefits, training, and recruitment constitute the majority of an organization's costs. Therefore, how the employees think and

behave at work - their attitudes and behaviours – can have a significant influence on the organization's input and output. By focusing on employee attitudes and behaviours, we can examine measurable, comparable results that contribute to productivity. This analysis can then support office design choices that are beneficial to employees. We cannot put a dollar value on the effect of one strategy, but we can show that changes that benefit employees also benefit organizations. P.3



Breakdown of an organization's expenditures. Based on Brill et al. (2001).

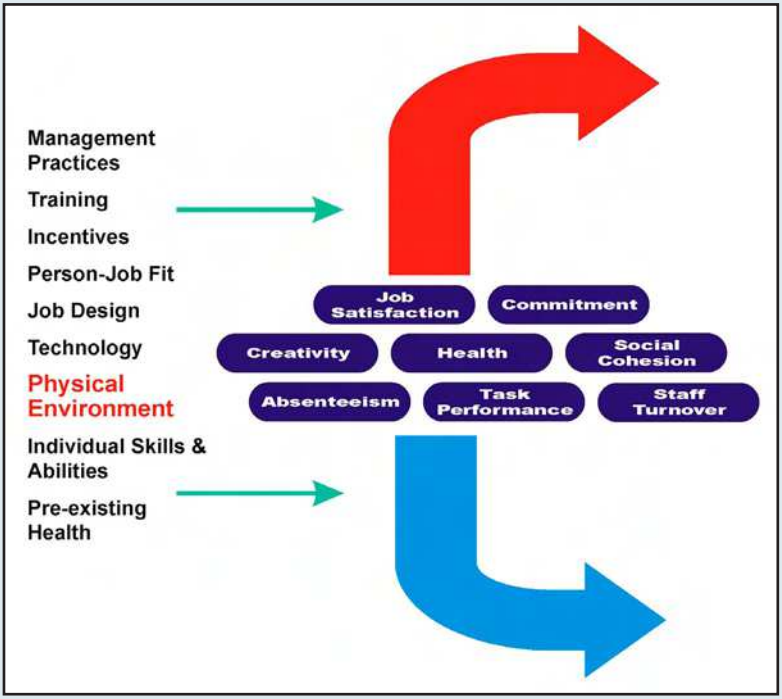
Employees and Organizational Productivity

Employee behaviours and attitudes include how satisfied workers are with their jobs, how committed they are to the organization, how they interact with co-workers, how frequently they are absent, how efficiently and creatively they complete their tasks, and whether or not they choose to leave the company. Employee health and well-being, while not strictly attitudes or behaviours, must also be considered in this list because of their significant effect on employee commitment, task performance, absence, interaction, satisfaction, etc. For many years, behavioural scientists have examined how these attitudes and behaviours are related to each other and how they influence the input and output of an organization.

For example, a study by Carlopio and colleagues validated the belief that satisfied employees are more committed to their organization and less likely to leave. A review by Podsakoff and colleagues concluded that satisfied and committed workers are more likely to put in extra effort at work, such as volunteering overtime or helping colleagues. In a study of almost 200,000 employees from 8,000 business units, Harter and colleagues found that those business units with higher average job satisfaction had lower staff turnover, higher customer satisfaction, and better business unit performance. Reducing staff turnover is a particularly important objective for organizations because it is estimated to cost up to twice a leaving employee's salary to find and train a replacement. P.4

Workers' health and well-being can also affect organizational productivity. Sick employees cannot work to their full cognitive capacity and may be absent. They may also require paid sick leave or make additional claims on health insurance. Statistics Canada reported that the average worker lost seven days due to illness or disability in 2001. In addition to physical sickness, Hardy and colleagues showed that employees with lower job satisfaction and psychological well-being (depression, anxiety) were more likely to be absent. The cost of employee absence includes not only lost work from the individual, but also disruption and performance losses for co-workers. The amount of work lost can be significant. P.5

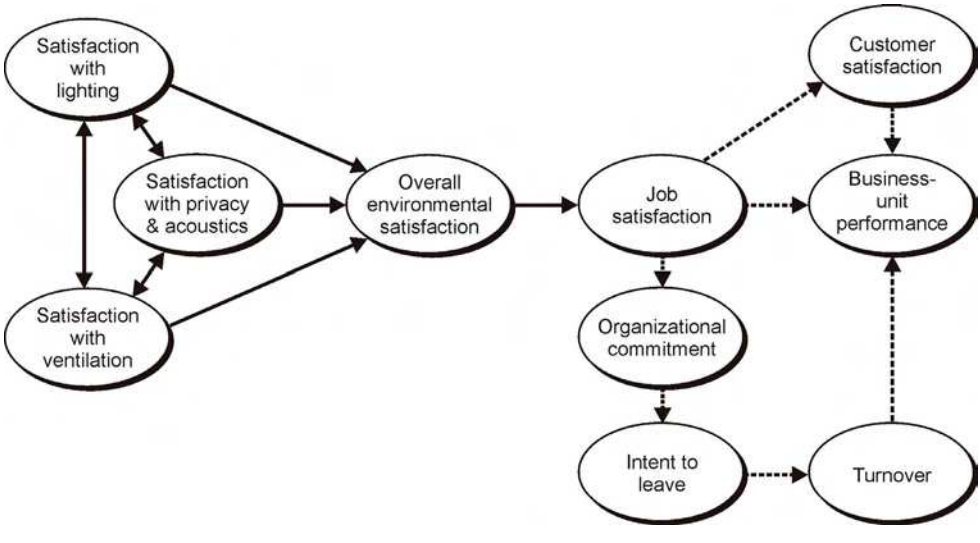
Relationships, like those above, demonstrate the importance of employees' attitudes and behaviours to the organization's productivity. Employees are often the organization's most valuable asset, and it is in the organization's interest to safeguard this investment. Initiatives that support employees, such as providing a suitable physical environment for them to work in, are very likely to promote organizational productivity.



Improving the Indoor Environment

Employee attitudes and behaviours are affected by numerous different factors, including management practices, employee-employer relations, salary

and non-monetary incentives, up-to-date technology, employees' skills and abilities, and opportunities for varied and stimulating work. For example, participatory and empowering management styles have a positive influence on job satisfaction, commitment, and well-being. Similarly, incentives such as salaries, pension schemes, on-site daycare and gyms, and company cars are factors that employees will consider when choosing to stay with an organization or move to a different company. P.6



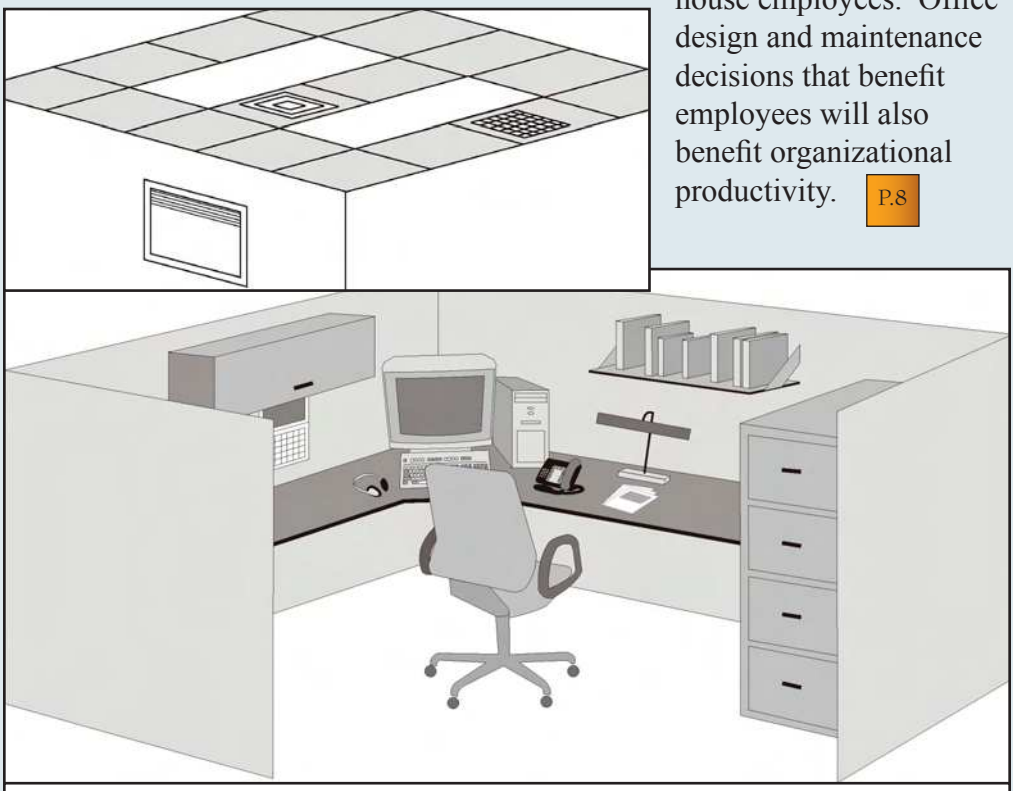
Satisfaction with the environment contributes to organizational success. COPE research focused on the solid arrow connections. The dotted arrow connections represent research from other sources. From: Veitch et al. (2004).

Improvements to the physical environment should also be considered another such incentive. The office conditions affect job satisfaction and all other attitudes and behaviours. A COPE survey of 779 open-plan workstations in nine public and private sector buildings in the U.S. and Canada found that satisfaction with the environment contributed to overall job satisfaction. From other reliable research, we can see how many other employee attitudes and behaviours are affected by job satisfaction and are, therefore, indirectly affected by the environment. The environment is not the only factor that can affect employees, but, considering how much time is spent in the office, it is a significant factor. Brill and colleagues estimated that the physical environment could, on average, account for 24% of the factors affecting job satisfaction, 11% for team performance, and 5% for individual performance. P.7

Organizations have historically been reluctant to spend money on the physical office environment because it is a direct cost to the business. Investments in buildings, furnishings, and operations usually entail an up-front expenditure, making the organization less cost-effective in the short-term while these

up-front costs are being absorbed. What is often forgotten is that people cost up to ten times more than the building and maintenance; therefore, an equipment or maintenance decision that makes it more difficult for people to do their jobs could end up costing the organization a lot more than their original investment or apparent up-front savings. Not only is investing in office design and management a sensible choice, it is also relatively easy to implement as compared to many business management initiatives. In addition, while changes that focus on specific staff members remain in place only as long as those employees are in the organization, changes to the physical environment can be beneficial to many employees using the space over time.

Improvements in office design and management are not the only consideration for organizational productivity, but they have an important role to play; offices should be considered as a potential asset rather than just a space to house employees. Office design and maintenance decisions that benefit employees will also benefit organizational productivity. P.8



Elements of the Workstation

The rest of this guide discusses research on the physical office environment and the ways in which it affects the employee. Research concerning office acoustics, indoor air quality, thermal comfort, lighting and daylighting, and workstation design and layout have been used to make recommendations that can guide office designers to more supportive environments, more satisfied employees, and more successful organizations.

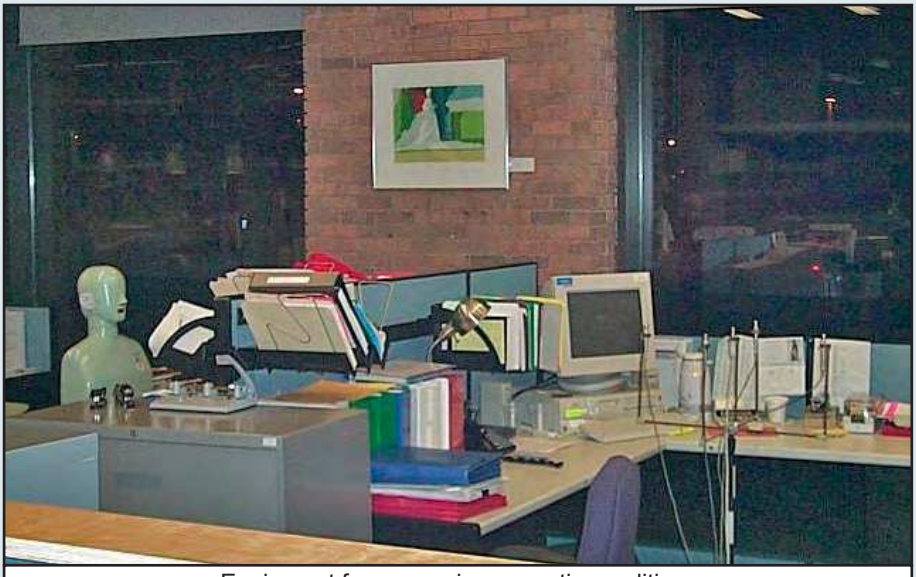
Acoustics

Practical tips: DO . . .

Provide acoustic satisfaction with comfortable background noise and good speech privacy;
Block sound with absorbent surfaces (especially the ceiling) and high, wide partitions;
Provide a sound masking system.

Practical tips: DO NOT . . .

Expose occupants to unacceptable noise sources, especially speech sources;
Create small workstations with low partitions;
Allow ambient sound to be distracting or unpleasant.



Equipment for measuring acoustic conditions

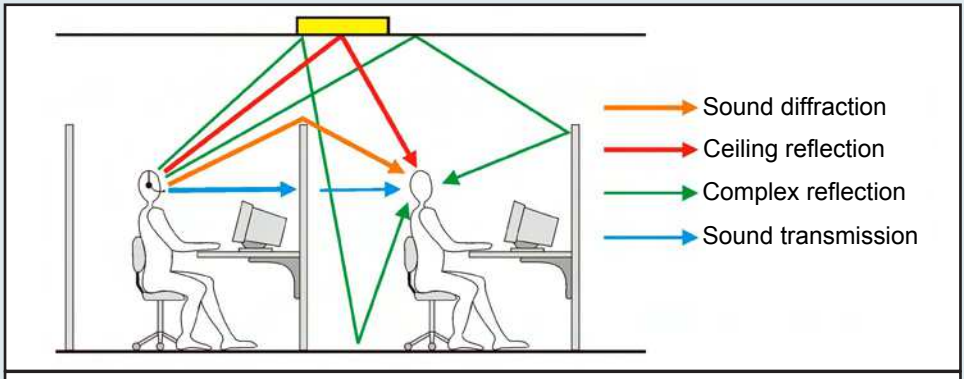
Acoustics in the Office

The Office Acoustic Environment

The acoustic environment in the office comprises all the sounds that occur throughout the day. Some of these sounds may be pleasant, such as music, or carry important information, such as a telephone ring or a fire alarm. However, when sounds are unwanted by the listener, they are perceived as noise: unpleasant, bothersome, distracting, or psychologically harmful. The information content, predictability, necessity, and controllability determine the noise annoyance. The most annoying noises contain information, and are unpredictable (irregular), unnecessary, and uncontrollable. A.1

When noise becomes a problem, most people close the door. Unfortunately, in open-plan offices, there are no full-height walls and doors to block noise, and many office sounds are audible at a distance.

All office sounds spread out in all directions from their sources and are reflected, absorbed, and transmitted when they strike surfaces. These sounds need to be controlled so that occupants are not disturbed by conversations and office equipment noises, and so that they do not disturb others.

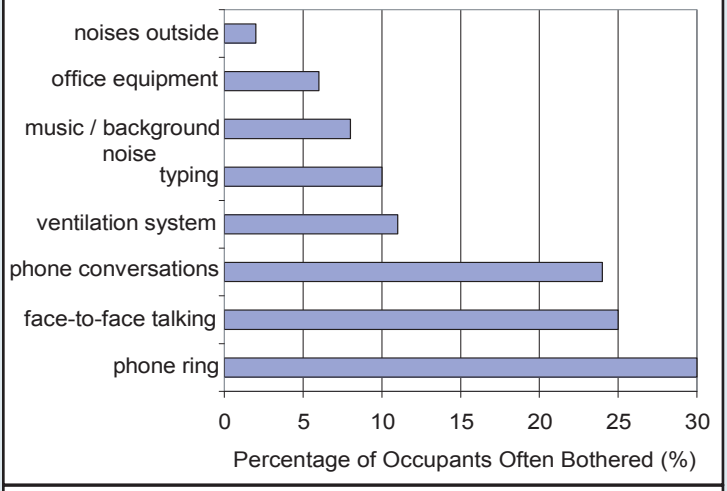


Sound propagation between two workstations

Problems with Acoustics: Too Much Noise

Employees name freedom from noise as one of the most important factors affecting their ability to work effectively. Noise has a negative effect on focus, task performance, comfort, stress levels and, indirectly, on organizational productivity.

A large survey of North American offices found that 54% of office workers were often bothered by noise: ringing phones and conversations were most disruptive. In the COPE field study, conversations and noise from others were the most frequently mentioned complaints about offices. A.2



Based on: Sundstrom et al. (1994).

Both continuous background noise and intermittent noises can be bothersome, but neither can be completely eliminated from the office nor should they be. Balanced sound levels provide privacy and prevent annoyance.

Creating a Good Acoustic Environment

Acoustic satisfaction for occupants requires speech privacy and comfortable sound levels.

When one has acceptable speech privacy, one cannot understand conversations overheard from other cubicles. It is a function of the ratio of sound energy from speech and other ambient sounds. If there were no ambient sound, overheard speech would be perfectly intelligible and very annoying because of its information content, unpredictability, and uncontrollability. A moderate level of ambient sound can cover speech sounds (or any other intermittent noise), and thereby, provide privacy to the speaker and prevent distraction to unwilling listeners. However, ambient sounds that are very loud become annoyances and should be kept within comfortable limits.

Designers should consider the following basic strategies: reduce noise levels at the source (i.e. speech, machine noise, telephone rings); reduce sound travel between workstations; create a neutral ambient noise to mask other noise.

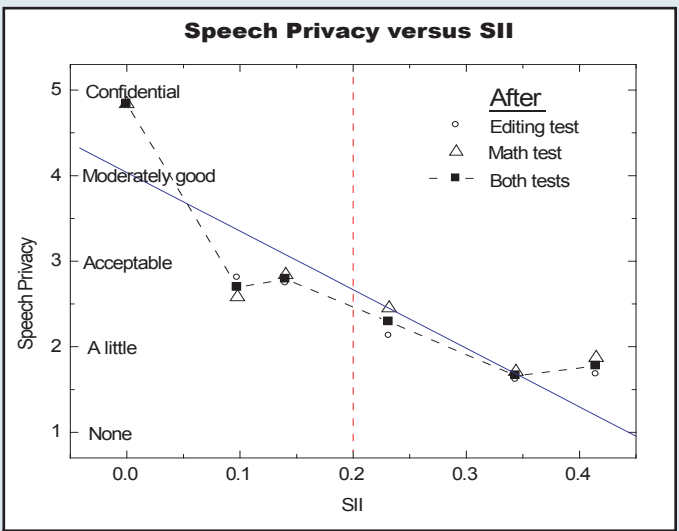
Organizational Productivity through Acoustic Design

Satisfactory Speech Privacy: SII 0.2

Good speech privacy allows occupants confidentiality for their actions and conversations while in the office and also limits distractions.

To identify good speech privacy, a physical index has been developed. Acousticians measured the intelligibility of words or sentences under conditions of varying background sound and then developed a statistical quantity that predicts intelligibility from the ratio of speech to background noise. The Speech Intelligibility Index (SII), which is very similar to the Articulation Index (AI), indicates how well speech can be understood in the presence of noise and ranges from 0 (perfect privacy) to 1 (perfect intelligibility). A.3

IRC studies have found that acceptable speech privacy in an open-plan office corresponds to a rating of SII 0.2 or less (AI 0.15 or less). Participants in a study rated their speech privacy as acceptable at SII 0.2. With SII levels over 0.2, occupants felt that they had very little privacy. SII levels lower than 0.2 would provide better speech privacy, but they are difficult to achieve in open-plan offices. SII 0.2 allows occupants an acceptable level of privacy and avoids major distractions. A.4

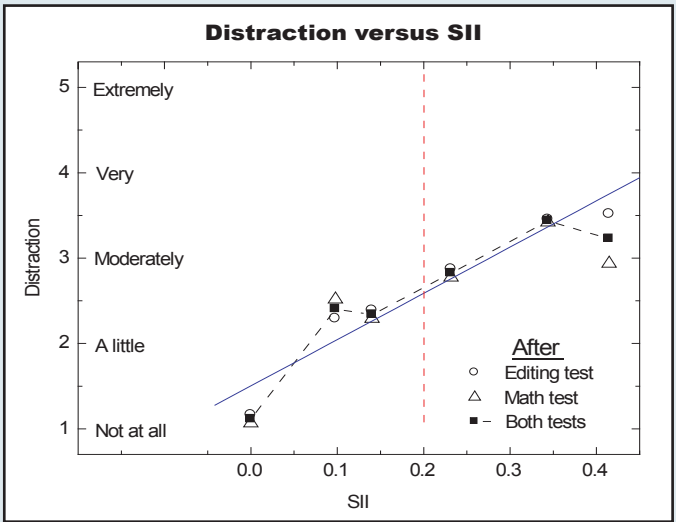


Occupants rated their sense of privacy under different SII conditions after editing and math tasks. The speech privacy conditions do not become acceptable until they approach SII 0.2. (Mean ratings: (a) after an editing task, (b) after a math task, and (c) the average of both.) From: Bradley & Gover (2003).

Research:
Distraction and Performance

Distracting noise has a detrimental effect on complex task performance. Memory and problem-solving decline with realistic office noise. Broken concentration reduces people's ability to make the creative leaps that distinguish merely acceptable solutions from the truly innovative. Noise level is not the principal problem: these effects are seen with unpredictable, intermittent noises. SII predicts subjectively rated distraction relatively well, and SII of less than 0.2 is needed to keep distraction at a low level.

A.5



Office occupants rated their level of distraction after math and editing tasks. Their distraction increased beyond acceptable levels when SII was higher than 0.2. (Mean ratings: (a) after an editing task, (b) after a math task, and (c) average of both.) From: Bradley & Gover (2003).

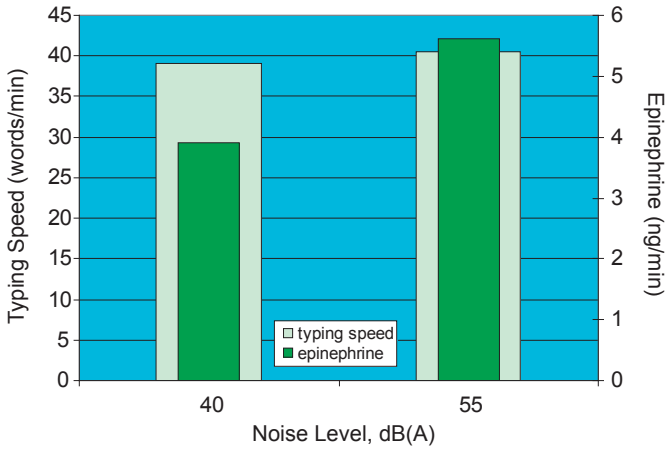
Ambient Sound

Ambient sound - preferably neutral in information content - provides the cover for speech and other noises and makes it possible to achieve SII 0.2. However, ambient sound becomes annoying itself if its volume exceeds 45-50 dB(A). The Canadian Standards Association recommends 45-48 dB(A) for open-plan office ambient sound. The figure on page 18 summarizes research on acceptable ambient sound. A.6

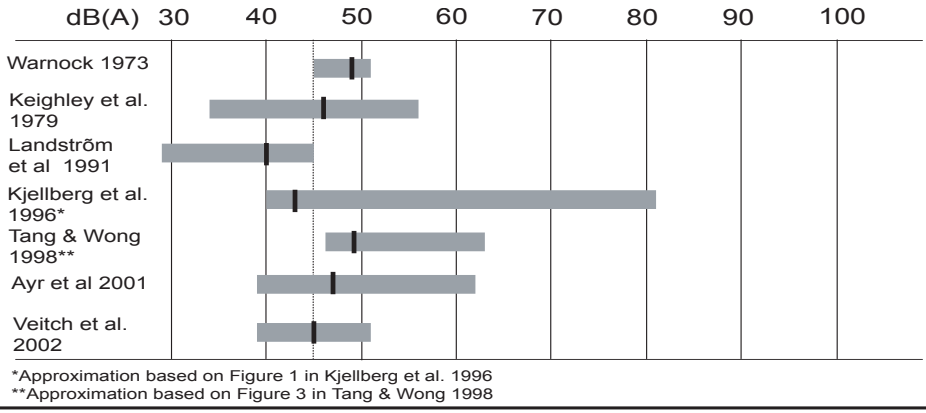
Research:
Noise and Stress

Loud noise is a well-known stressor and affects physiological functioning. In an office simulation experiment, Evans and Johnson compared office workers under 40 dB(A) and 55 dB(A) conditions. Workers perceived the louder condition as more noisy but not more stressful, and typing performance was unaffected. However, occupants made fewer postural adjustments, showed physiological stress indicators, and were less tolerant of frustration. Over the long-term, occupants would have been at risk for musculo-skeletal disorders and health problems. This study shows that louder conditions can be harmful even when people are not fully aware of any adverse effects. Other studies support these results. Melamed and colleagues found that people exposed to noise at work showed elevated blood pressure, especially in more complex jobs.

A.7



This study measured typing performance and epinephrine secretion (a physiological indicator of stress) at two noise levels. Occupants maintained performance, but their stress response increased with the noise. Based on: Evans and Johnson (2000).



The grey bars indicate the ranges of sound levels tested or measured in each study. The black markers indicate the highest sound levels associated with satisfaction. IRC reviewed this literature for COPE. From: Navai & Veitch (2003).

Sound Masking Noise: In order to achieve the noise ratio necessary for SII 0.2, office designers should consider sound masking. Sound masking systems can be used to add neutral background noise that will cover (mask) speech sounds and other distracting noises. The noise level and spectrum created by a sound masking system must be carefully designed to fit the acoustical conditions of the particular office space and must be distributed evenly throughout the space.

Research: Masking Sound

Masking sound is an effective way to lower SII and create good acoustical conditions. Laboratory simulations have found that masking sound improves complex cognitive tasks and reduces perceived stress. COPE research found that masking noise contributed to acoustic satisfaction, and Banbury et al. recommend masking sound to reduce distraction.

A.8

The masking sound needs to be loud enough to effectively cover office noise, but not so loud that it creates a disturbance itself. Sound masking devices with noise levels between 45-48 dB(A) are acceptable. The masking noise must also have a balanced high-low frequency spectrum so that unwanted speech sounds are masked without creating annoying hissing or rumbling. A professional can create the right masking sound for a space. A.9

Office Characteristics

Controlling ambient sound is only one part of creating satisfactory acoustic conditions and speech privacy. Annoying noises, like speech, printer noise, typing, and telephone rings, also require control. Noise sources can be isolated and reduced, and travelling sound can be absorbed and blocked with good office design and layout so that noises, such as speech, do not transmit from one workstation to another.

The best way to control noise sources is through office design. The acoustic properties of the office can significantly reduce sound travel by blocking sound transmission and by absorbing reflected sound. Sound Transmission Class (STC) ratings indicate how well a material reduces sound propagating through it (sound transmission). Sound Absorption Average (SAA) ratings indicate how well the material absorbs sound hitting the material. The following table shows material properties recommended for open-plan offices.

Choosing the best design

Research on noise for IRC's COPE project showed that the absorption properties of the ceiling, the workstation size, and the partition height have the largest effect on acoustic conditions since they are compensating for walls that would normally block sound travel between neighbours; however, no one element can control noise, and the most significant improvements in office acoustics occur when most of the office elements are well designed.

The following recommended office properties can help create SII 0.2. Consult the PWGSC-sponsored design guide produced by IRC (Warnock, 2004) for more detailed guidance on achieving desired acoustic conditions. A.10

ACOUSTIC PROPERTIES	
Element	**Acoustical Properties**
Exterior Walls	STC 50
Windows	STC 35
Ceiling	SAA >0.90
Floors	STC 55 (carpeted)
Partitions	SAA >0.70 STC 20
Based on: Canadian Standards Association (2000), and Bradley (2004).	
Most manufacturers provide the acoustic properties of their products.	

Partition height: Partitions need to be high enough to block sound paths between occupants; this can be achieved by blocking sight lines between occupants at their most common task locations and orientations. The Canadian Standards Association recommends partition heights between 1.5 m and 1.8 m (59-72 in.) high. COPE research recommends partition heights greater than 1.6 m (64 in.); partition heights greater than 1.7 m (66 in.) would be ideal. Partition height can also affect light distribution and perceptions of air flow: consider all aspects of the indoor environment when choosing partition height.

Workstation size: Sound diminishes over distance; therefore, larger workstations reduce the amount of noise that reaches neighbours. COPE research recommends workstation sizes of 6.3 m^2 (67 ft^2) or greater.

Orientation: The orientation of workstation openings and of occupants can reduce the level of noise that travels around the office. Groups of workstations should be carefully arranged to avoid noise reflection out of one workstation into others. Occupants working in adjacent workstations should be seated so that they are facing away from each other. Speech is then directed away from neighbours.

Workstation arrangement: In this office, direct, diffracted, and reflected sound paths have been blocked by partition placement and orientation. The partitions are high; noise sources such as occupants and printers are isolated; and occupants are oriented away from each other within their workstations.

Office Layout: It is important to isolate noise sources. Designers should locate shared, noise-generating resources – such as meeting rooms, group discussion areas, lunch rooms, printers, photocopiers, main traffic corridors – away from workers who need quiet to concentrate on their tasks. Direct sound paths between workstations should also be avoided. One solution is to arrange shared resources along a main path, and locate individual workstations along quieter, less travelled paths.

The layout of luminaires in relation to partitions can also contribute to sound propagation by reflecting sound between workstations. Parabolic-louvred luminaires centred over the workstation, prismatic-lensed luminaires over partitions, and certain lenses for indirect luminaires can be problematic. Luminaires and their placement should be considered during acoustic design.

Office Etiquette: Reductions in noise, particularly distracting speech, can also be achieved by introducing an office etiquette policy. A policy that encourages open-plan office workers to speak more quietly, use headphones for music and radio, avoid speaker phones, and be aware of the noise they generate will help to solve noise problems.

Office etiquette policies should also be supported by providing alternative facilities, such as private meeting rooms, lunch or social rooms, even phone conversation rooms, where employees can carry out noisier activities.

COPE-Calc

As part of the COPE project, researchers developed software that helps to predict the acoustic conditions in open-plan offices by modelling the design conditions set by the user. Users can set their office characteristics (partition height, ceiling absorption, partition absorption, etc.), listen to a sample of the sound environment, and read suggestions for improving the design.
Available at: http://irc.nrc-cnrc.gc.ca/ie/cope/07.html

Indoor Air Quality and Thermal Comfort

Practical tips: DO . . .

Provide an adequate supply of outdoor air;
Provide some individual control over temperature, air velocity, and/or air direction;
Clean and maintain the ventilation system and the office space;
Create a comfortable thermal environment;
Insulate windows and provide perimeter heating/cooling.

Practical tips: DO NOT . . .

Exceed air supply capacity of ventilation system;
Choose furnishings and equipment that emit high levels of contaminants;
Place occupants close to contaminant sources;
Block air diffusers or create draught;
Use very high partitions;
Ignore occupant complaints and symptoms.

Supply air diffusers

Office Climate: Ventilation and Temperature

Indoor Air and Thermal Climate

In any office, indoor air quality (IAQ) and thermal conditions are determined by the building's ventilation system and by the contents of the office. Poor conditions can result if contaminants, air delivery, and temperature are not properly managed.

In North America, most office buildings are mechanically ventilated. The building is sealed and relatively airtight; outdoor air is brought into the building through the ventilation system.

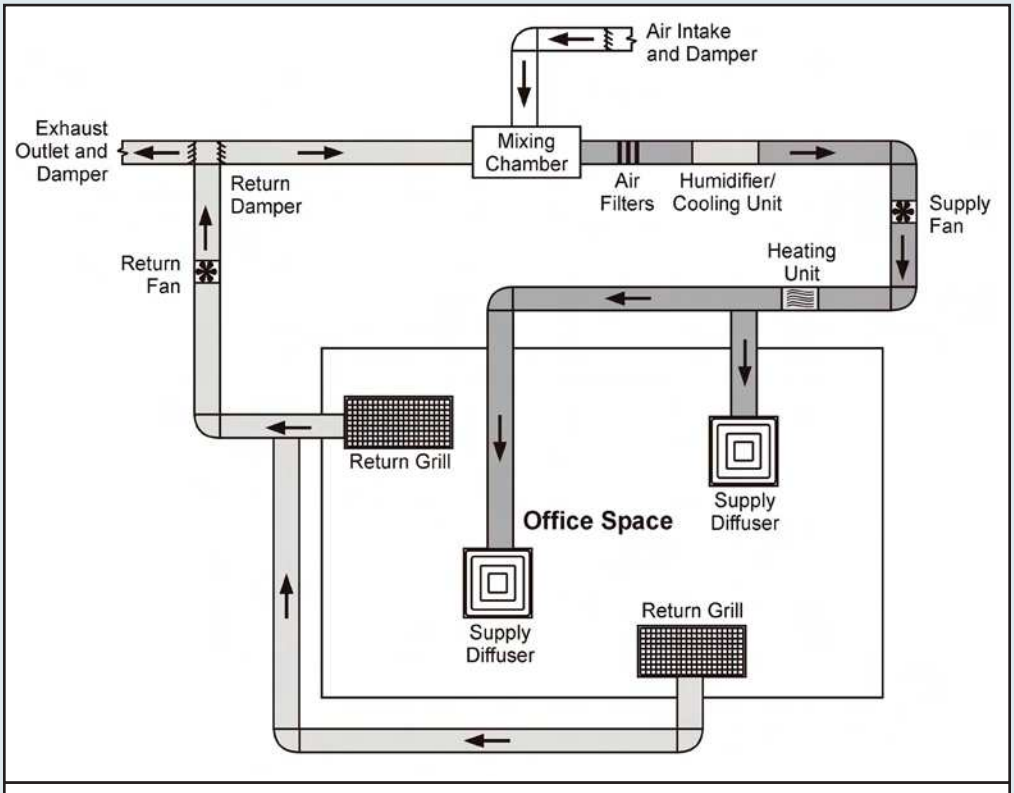


Diagram of the basic elements of a mechanical ventilation system.

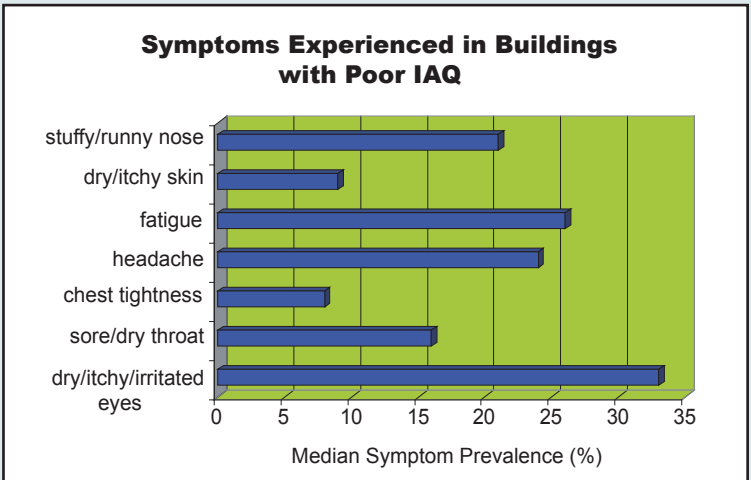
The ventilation system takes air from outside, filters it, heats or cools it, humidifies or dries it, and delivers it to the interior. Older air is removed from

the interior and some is exhausted from the building. The remainder (typically 80-85%) of the older, return air is recirculated with the outside air.

The office environment is as important a factor as the ventilation system because occupants, equipment, and materials can create contaminants; equipment and windows can be local heat, cold, and draught sources; and the placement of occupants relative to air supply diffusers can influence the air quality and thermal conditions experienced. Open-plan offices, in particular, tend to be more densely populated than individual closed offices, and the increase in occupants, furnishings, and equipment can affect contaminant concentrations and thermal conditions. These office design factors have to be considered along with ventilation system operation and maintenance.

Satisfaction with IAQ and the Thermal Climate

Poor IAQ and thermal comfort are among the most common problems in offices. Poor conditions can be uncomfortable and make it harder to concentrate and work efficiently. They can also lead to symptoms such as headaches, drowsiness, or eye, nose and throat irritation. Researchers have recorded that approximately one third of employee sick leave can be attributed to symptoms caused by poor IAQ. I.1



Occupant symptoms in 63 U.S. office buildings were investigated by the National Institute for Occupational Safety and Health (NIOSH) because of frequent IAQ complaints. Based on: Mendell et al. (1999).

For an office to support organizational productivity, the conditions need to be comfortable, healthy, and relatively adjustable so that they can respond to individual preferences and changing needs.

Creating the Indoor Environment

The ideal office environment requires comfortable temperature and humidity, an adequate supply of clean outdoor air, appropriate air distribution within the space, low levels of contaminants, and good communication between building occupants and building operators.

Indoor Air Quality:

The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) has defined IAQ as indoor air that is free of contaminants at harmful levels and that satisfies a significant majority (80% or more) of occupants.

Thermal Comfort:

Thermal comfort, according to ASHRAE, is achieved when a significant majority (80% or more) of occupants are satisfied with the thermal conditions of the space. I.2

Considering that both the office conditions and the ventilation system contribute to IAQ and thermal conditions, both office designers and building staff are implicated in achieving occupant health, comfort, and effectiveness. The operation of the mechanical ventilation system has to be coordinated with the local office elements in order to achieve good office conditions.

IRC and PWGSC collaborated to produce three manuals about IAQ for property owners, facilities managers, and building operators. These guides provide detailed information concerning the procedures for ventilation system operation, problem prevention, problem diagnosis, and occupant-building staff communication. I.3

Organizational Productivity through IAQ and Thermal Comfort

Indoor Contaminants

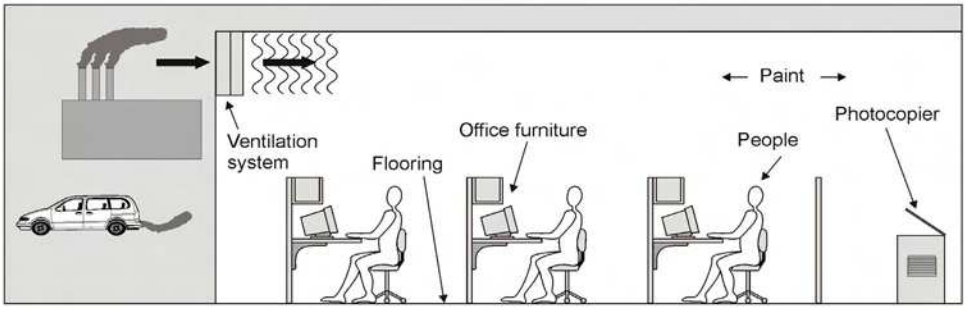
IAQ is mainly determined by the concentrations of contaminants in the office space. Contaminants can be created by people and equipment indoors or can enter the space from outside.

There are many types of contaminants that come from a variety of sources. Contaminants, such as carbon monoxide, sulphur dioxide, radon, and lead, occur primarily outside, either naturally or from vehicle emissions and industrial processes; they enter the office through the ventilation system or air leaks in the building envelope. Ozone can enter from outside and is also produced by printers and photocopiers. Particles such as dust, fibres, pollen, and animal dander get into the office with outdoor air or are shed by furniture, equipment, and people. Mould spores also enter with outdoor air and can grow in the office or in the ventilation system if conditions are damp. Volatile organic compounds (VOCs) are additional chemical contaminants, which can occur in the office. They are released slowly over time by office furnishings, building material, paints, stains, adhesives, personal hygiene products, and cleaning products. All these contaminants, from all sources, must be controlled to provide good IAQ and healthy environments. I.5

Research:
Effect of Contaminants

The presence of contaminants can make the air feel dusty and stale, produce unpleasant odours, and lead to discomfort and dissatisfaction. Contaminants have also been associated with increased symptoms such as eye/nose/throat irritation, dizziness, headaches, drowsiness, fatigue, and breathlessness. Symptoms reduce task performance and satisfaction, and increase sick leave. Wargocki and colleagues found that occupants typed slower, made more errors, and experienced more headaches, nose dryness, throat irritation, and odour annoyance in the presence of a contaminated carpet.

I.4



Indoor and outdoor contaminants sources that can affect IAQ in the office

For some contaminants, recommended maximum concentrations exist to guide practitioners. Organizations such as the U.S. Environmental Protection Agency (EPA), Health Canada, and the World Health Organization (WHO) have established maximum concentrations designed to maintain occupant health and comfort in non-industrial environments. 1.6

ACCEPTABLE CONTAMINANT CONCENTRATIONS			
	U.S. EPA	**Health Canada**	**WHO**
Carbon Monoxide	9 ppm [8 h]* 35 ppm [1 h]	11 ppm [8 h] 25 ppm [1 h]	10 ppm [8 h] 25 ppm [1 h]
Formaldehyde		0.05 ppm [L]	0.081 ppm [30 min]
Lead	1.5 µg/m^3 [3 mths]	Minimize exposure	0.5 µg/m^3 [1 yr]
Nitrogen dioxide	0.05 ppm [1 yr]	0.05 ppm [8 h] 0.25 ppm [1 h]	0.004 ppm [1 yr] 0.1 ppm [1 h]
Ozone	0.12 ppm [1 h] 0.08 ppm [8 h]	0.12 ppm [1 h]	0.064 ppm [8 h]
Particles <2.5 µm	15 µg/m^3 [1 yr] 65 µg/m^3 [24 h]	0.04 mg/m^3 [L] 0.1 mg/m^3 [1 h]	
Particles <10 µm	50 µg/m^3 [1 yr] 150 µg/m^3 [24 h]		
Radon	4 pCi/L [1 yr]		2.7 pCi/L [1 yr]
Sulphur Dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h]	0.019 ppm [8 h] 0.38 ppm [5 min]	0.012 ppm [1 yr] 0.048 ppm [24 h]

*Average concentration over the [exposure time] given; [L] refers to long-term exposure.
Based on: ASHRAE (2003).

Carbon dioxide (CO_2) concentrations can also be used as an indirect measure of IAQ and contaminant build-up. Concentrations are unlikely to reach harmful levels in offices, but elevated levels may signal a problem.

ASHRAE recommends CO_2 levels below 1,000 ppm. (Recommended CO_2 levels do not guarantee acceptable levels of all other contaminants.) I.7

For other contaminants (notably VOCs and mould) no recommended concentrations have been established because it is difficult to collect data on long-term exposure to these potentially harmful contaminants and to define the complex relationships between multiple contaminants and occupants. Where no specific recommendation exists, contaminant levels should be kept as low as possible.

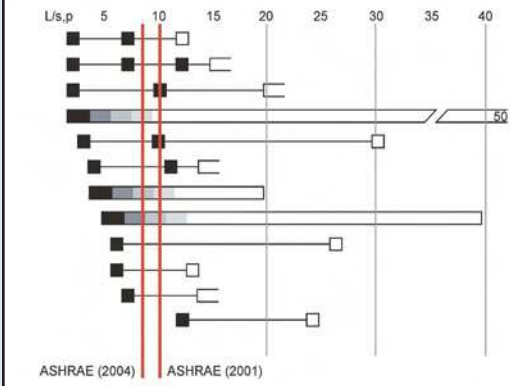
Ventilation: Air Supply

Mechanical ventilation provides outdoor air to the office to dilute contaminants; it also creates the air movement that forces supply air to circulate and old air to be removed via the return air grilles. Dilution and removal are essential for contaminant management, good IAQ, and occupant comfort and effectiveness.

Research: Outdoor Air Supply

Low outdoor air supply rates are associated with reduced occupant satisfaction and task performance, and with increased symptoms and absenteeism. Many studies compared rates above and below 10 Litres per second per person, L/s.p, (20 cubic feet per metre, cfm) to examine the effect on health and satisfaction (10 L/s.p. was ASHRAE's recommended standard for many years.). ASHRAE has recently reduced its recommendation to 8.5 L/s.p, which will lead to energy savings, but the effect on occupants is unclear because the two rates have not been compared. I.8

Outdoor Air Supply Rate and Occupant Response



A COPE review found 12 out of 17 studies that observed higher occupant problem rates (dark boxes) at lower outdoor air supply rates. Based on: Charles & Veitch (2002).

Outdoor Air Supply Rate: Office spaces need to be ventilated with sufficient outdoor air to dilute and remove contaminants and provide occupants with clean air to breathe. ASHRAE recommends a minimum outdoor air supply rate of 8.5 L/s.p (17 cfm); however a rate of 10 L/s.p (20 cfm) is preferable. I.9

Building maintenance officials establish the outdoor air supply volume for a space based on the number of occupants. For a healthy volume of outdoor air to be delivered, occupant density should not exceed the ventilation system's outdoor air supply capacity, and accurate information on office density must be given to the professionals setting up and maintaining the system. Changes in the number of occupants must also be reported so that the outdoor air supply can be adjusted accordingly.

Recommended outdoor air supply rates are intended for regular contaminant levels. When high levels of contaminants occur, the outdoor air supply rate should be increased. When possible, an outdoor air supply rate of 20 L/s.p (40 cfm) should be used for two to four weeks after renovations or when new contaminant sources have been added to the office space. (Paint, floor coverings, office furniture and other materials emit higher levels of contaminants when newly installed.) Once contaminant emissions have returned to normal levels, the outdoor air rate should be reset. I.10

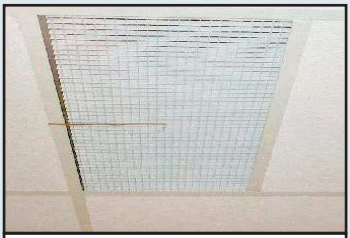
Air Delivery: As well as maintaining a suitable outdoor air supply, it is important to make sure that outdoor air reaches all occupied parts of the office space. The placement and type of supply diffusers and return air grilles influence how air moves within the space. Most North American offices use supply diffusers and return grilles mounted on the ceiling, and configured so that supply air mixes as thoroughly as possible with the air in the room. When properly set-up and operated, this method of air delivery can achieve acceptable IAQ in the space. Other air delivery systems, such as displacement delivery or personal air delivery, can also provide satisfactory IAQ. As an added benefit, personal air delivery systems also allow occupants some control over their conditions.

Research: Air Delivery

In COPE lab research, workstation size and partition height had little effect on air delivery in an open-plan office with ceiling-mounted diffusers and an outdoor air supply rate of 10 L/s.p (20 cfm). (The results depend on a properly configured and operated ventilation system, without which poor IAQ is likely regardless of the office configuration.) The COPE field study found that occupants with higher partitions tended to be less satisfied with air quality. This finding is likely to be a psychological effect, with occupants perceiving that high partitions interfere with acceptable airflow. I.11

To maintain the intended air distribution, diffusers have to remain unblocked. Furnishings should not be placed on top of, or in front of, diffusers, which must remain open. The placement and number of supply diffusers and return

grilles may also have to be altered when creating or reconfiguring an open-plan office. Partition height should also be considered: partitions higher than 1.7 m (66 in.) create the impression of poor airflow, even though they do not affect air distribution. Partition height also affects other aspects of the indoor environment and all the implications must be considered when choosing partitions. I.12



Return grille

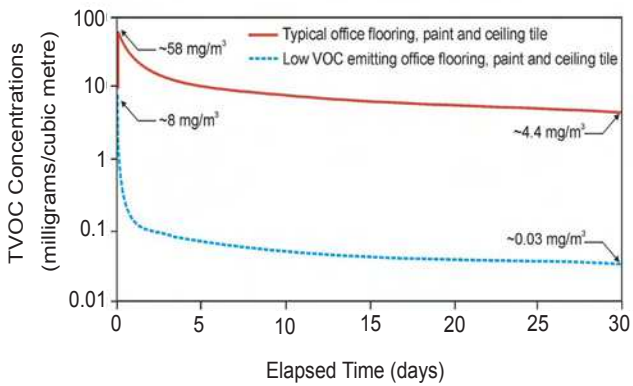
Linear ceiling-mounted diffuser

Square ceiling-mounted diffuser

Source Control

Contaminant control depends on a number of additional processes besides adequate ventilation. Prevention, cleaning, and isolation should be used to control contaminant sources and keep contaminant levels low.

Prevention: When and where possible, contaminants should be prevented from entering the indoor environment. Office furnishings, equipment, paint, and cleaning products should emit as few contaminants as possible and should not release any one contaminant in concentrations that create symptoms. Manufacturers can provide information on the emissions from their products. High-quality filters should also be used in the ventilation system to prevent particulates from circulating with the supply air. I.13



This graph compares VOC emissions from typical office flooring, paint, and ceiling tile with low VOC-emitting alternatives. These results were simulated for a 30,500 m^2 office space using a database of material emissions and a simulation program developed at IRC. PWGSC is a sponsor of IRC's ongoing material emissions research.

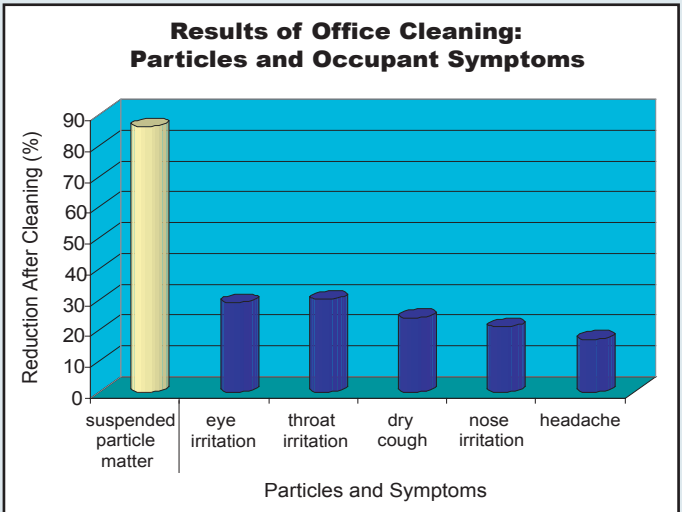
Cleaning: The office space should be cleaned regularly to remove contaminants such as particles and mould. Cleaning should be conducted when the occupants are absent so that both the contaminants from cleaning products and the particles stirred up will not be bothersome.

It is also important to ensure that the mechanical ventilation system is cleaned and maintained regularly so that it does not become a contaminant source itself. Humidifiers can be a habitat for mould, particularly if they are dirty or contain stale water. Dust accumulation and micro-organisms in air supply ducts can also contaminate the office space. Air filters can be a source of contaminants and odour if VOCs and mould are present in the particles collected by the filter. Filters can also be inefficient when not changed as directed. Regular maintenance is essential for contaminant reduction and acceptable IAQ.

Research:
Cleaning

Research shows that regular cleaning of the office space reduces contaminants and improves occupant satisfaction and symptoms. Research also indicates that contaminants in ventilation components can reduce perceived IAQ for occupants and increase odour irritation and other symptoms.

I.14



A thorough cleaning of the office significantly reduced the particles, and improved occupant symptoms. There was no substantial change in offices where no cleaning took place. Based on: Kemp et al. (1998).

Isolation: When sources emitting high contaminant levels are present, they should be isolated from occupants. Equipment, such as printers and photocopiers, should be located in a separate room or workstation, away from occupants. If equipment is a source of particularly high contaminant levels, direct exhausting should be considered: a dedicated exhaust grille at the source removes the contaminants and prevents them from being recirculated through the ventilation system.

This printer has been placed in a room of its own, with a door and a dedicated exhaust system so that contaminants do not circulate in the office. (The door also isolates the noise annoyance of the printer.)

Thermal Comfort

Comfortable thermal conditions in mechanically ventilated buildings depend on the temperature, air velocity, and relative humidity in the space, and occupant activity level and clothing insulation. These factors affect the human body's physiological processes (such as sweating and shivering), and therefore influence whether the body has a comfortable thermal state. Thermal comfort requires comfortable overall thermal sensations and also comfort on particular body parts.

Research: Temperature

Research shows that a hot or cold environment reduces comfort and task performance. Hot environments can also cause fatigue, difficulty concentrating, headaches, and perceptions of poorer IAQ. Occupants typically prefer moderate temperatures.

Research: Humidity

Humidity is desirable. Without it, occupants can experience problems with dry eyes, nose, throat or skin, and static electricity. However, excess humidity is also problematic because it increases the risk of infection, promotes mould and bacteria growth, and amplifies discomfort.

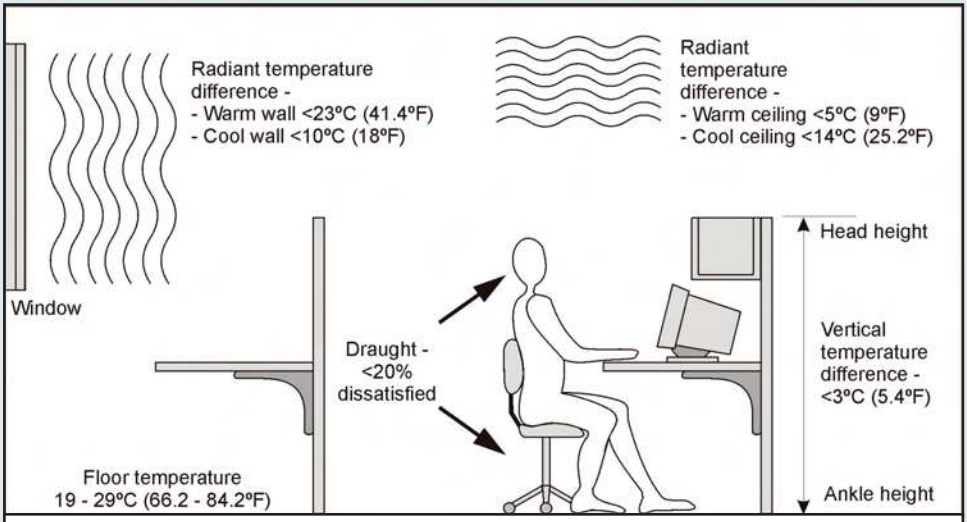
I.15

Overall Thermal Comfort: ASHRAE has established overall temperature and humidity recommendations that help create thermal comfort. I.16

ACCEPTABLE OPERATIVE TEMPERATURES		
	Conditions	**Acceptable Operative Temperatures**[a,b]
Summer	Relative Humidity 30%	24.5 - 28°C (76-82°F)
	Relative Humidity 60%	23-25.5°C (74-78°F)
Winter	Relative Humidity 30%	20.5-25.5°C (69-78°F)
	Relative Humidity 60%	20-24°C (68-75°F)

a: Assumes sedentary office activities and air velocity less than 0.2 m/s (40 fpm).
b: Operative temperature is a combination of air temperature and radiant temperature. For relatively uniform environments, radiant temperature is equal to air temperature.
Based on : ASHRAE (2004).

Local temperature differences: Discomfort can occur from warm or cool walls, windows, ceilings and floors, or from vertical differences in temperature. Local temperature differences should be maintained within the ranges shown in the diagram below. Providing perimeter heating/cooling, insulating windows, providing individual control over air delivery, and isolating heat/cold generating equipment can all help to control local temperature differences. I.17



Recommended local thermal comfort conditions. Based on: ASHRAE (2004).

Draught: Draught is local air movement that cools an occupant uncomfortably and is the most common form of local thermal discomfort. The discomfort from draught depends on temperature, air velocity and the amount of fluctuation in the airflow. People are particularly sensitive to draughts at the head and ankles. The risk of draught can be minimised by maintaining air velocity below 0.2 m/s (40 fpm) and by directing the air supply away from occupants. I.18

Research:
Draught

IRC research for COPE found that certain supply diffuser/workstation geometries can increase the risk of draught. Diffusers angled at occupants and smaller workstations can be problematic because occupants are directly in the path of the air and are not able to move easily. Research also suggests that draughts can be welcome in hot, humid conditions because of the cooling effect they provide. ASHRAE recommendations allow for higher air velocities in these conditions, provided that occupants have personal control over the air speed and direction.

I.19

Personal Control and Adjustability

Controls and office policies can be used to provide occupants with additional means by which to satisfy their particular air quality and thermal comfort needs.

Thermal Comfort Policies: Flexible dress codes can allow occupants to satisfy their thermal preferences. When single thermostat settings affect multiple users, policies on thermostat adjustment and window use may also be necessary.

Controls: Personal or office-wide ventilation and thermal controls can be provided for occupants. These controls can be thermostats or personal air supply diffusers that allow the adjustment of air direction and velocity.

Personal ventilation control that allows the occupant to set the temperature for his or her cubicle.

An alternative air delivery method is an individual supply of air for each workstation, using diffusers in the floor, ceiling, or mounted on the desk. Most personal air delivery systems also give occupants control over their individual supply air velocity and direction, giving them the opportunity to adjust the conditions to suit their personal preferences.

Research:
Personal Air Delivery

Personal air delivery has been associated with improved satisfaction and reduced symptoms as compared to traditional delivery. One study found that occupants with desk-mounted personal air delivery were more satisfied with ventilation, odour, and thermal conditions, as compared to occupants with traditional delivery. PWGSC field tests have noted that the number of trouble calls from people dropped when they had individual controls over ventilation.

I.20

Floor-level supply diffuser

Personal, ceiling-mounted supply diffuser

Communication and Complaint Records: Clear and regular communication should be established between all parties involved in office IAQ and thermal comfort. Occupants have to be involved in problem prevention, and should make note of symptoms, odours or physical signs (such as dust/debris on the air supply and return grilles). Complaint details should be recorded and reported to the appropriate officials. Occupants should also be aware of cleaning and maintenance performed by the building staff.

Lighting and Daylighting

Practical Tips: DO . . .

Provide adequate task illuminance;
Provide access to daylight;
Provide uniformity on task surfaces;
Create visual interest and a pleasant atmosphere;
Use electronic ballasts;
Use fluorescent lamps with good colour rendering;
Provide some individual lighting controls.

Practical Tips: DO NOT . . .

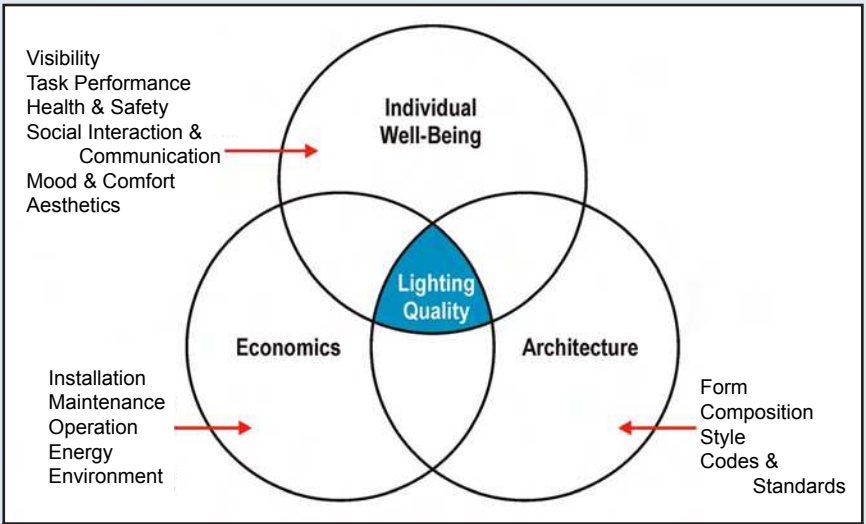
Allow walls and ceilings to be dark and cave-like;
Permit glare problems;
Create a colourless, blandly uniform office;
Use glossy surfaces;
Use magnetic ballasts with fluorescent lamps.

Luminaire choices for open-plan offices

Quality Lighting Design

Dimensions of Good Office Lighting

Light reflected off surfaces and objects reveals the world to us. Good interior lighting reveals what we need to see, making details visible but also facilitating communication, setting the mood, and addressing health and safety. It does so in balance with the architectural characteristics of the space and practical considerations such as costs, energy consumption, installation, and maintenance.



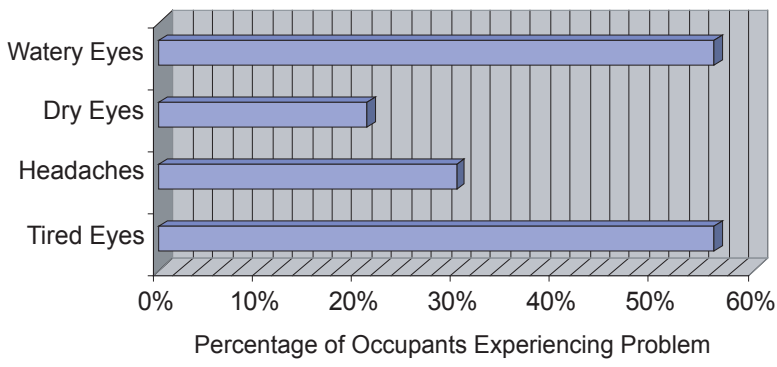
This model of quality lighting was developed at the NRC in the 1990s and appears in the IESNA Lighting Handbook.

Specifying office lighting starts with knowing the architectural features of the space, who will occupy it, and what they will do. Much of 20th century research focused on helping people see small, low-contrast details like 4th-generation carbon copies. Now, many such tasks have disappeared to be replaced with other, varied office tasks and their differing lighting requirements. Today, lighting conditions must provide appropriate lighting for all the different tasks that are done in the space. In open-plan offices, there are many occupants of varying ages, preferences, and abilities doing a large variety of tasks, and the target lighting conditions should satisfy each of these needs. Office lighting conditions must also facilitate communication, provide suitable directionality to reveal facial expressions and body language, and respond to health and safety considerations, which include preventing visual discomfort and providing the required emergency lighting. L.1

Lighting professionals describe the target lighting conditions in many dimensions, including light levels (illuminances and luminances), control over glare, distribution, uniformity, and light source colour. For open-plan office settings where the most common tasks involve intensive computer use, the most important lighting dimensions are light levels (vertical illuminance and room surface luminances) and glare control (direct and reflected glare control including source/task/eye geometry). L.2

Lighting a Space for the Occupants

When lighting fails to meet the target lighting conditions and occupant needs, occupants notice. One survey found that 86% of respondents believed that improvements in lighting would reduce the incidence of symptoms, such as dry or watery eyes and headaches. Conversely, people who rate their lighting as being of higher quality also rate their offices as more attractive, are in a more pleasant mood, and have fewer symptoms of visual or physical discomfort at the end of the workday. L.3

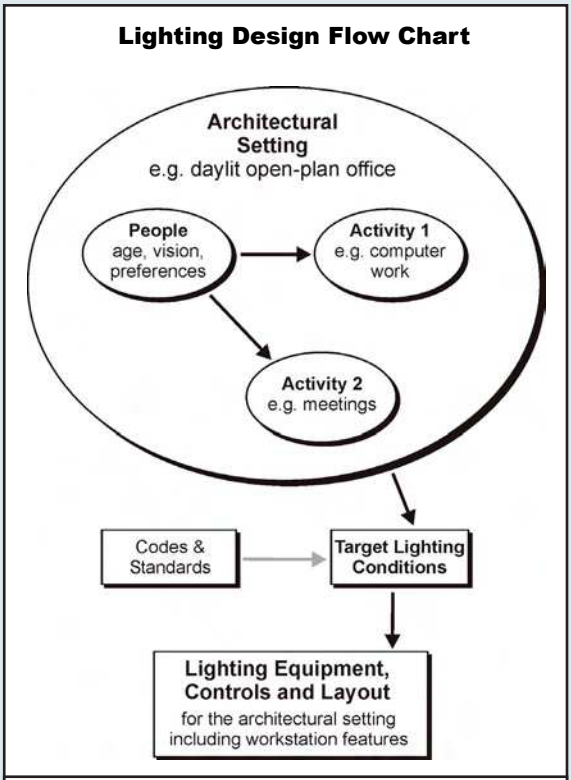


All of these symptoms can be linked to poor lighting. The majority of participants felt that these problems would improve with improved lighting. Based on: Steelcase (1999).

Designing Good Office Lighting

Lighting design is a two-step process of considering users' visual task requirements and the organization's aesthetic and image projection to

determine the target lighting conditions; then, choosing appropriate lighting equipment, controls, and placement so that the target conditions are met. Decisions on electric lighting dominate this process, but good lighting design also includes decisions about equipment to control and direct daylight, furnishings, paint, and office layout, all designed for the occupant and his or her tasks.



Lighting design flow chart. All of these elements must be considered to ensure quality lighting design.

Important Lighting Terms

Illuminance is the density of light energy falling on a surface; it is measured in lumens/metre^2 [lux].

Luminance is the amount of light coming off a surface, and is measured in candelas per square metre [cd/m^2]. Luminance produces the sensation of brightness and is a function of the illuminance on a surface and that surface's reflective properties.

Glare is too much luminance in the wrong place and has two effects: disability and discomfort. Disability occurs when excess light obscures details. Discomfort occurs when excess light causes pain. Glare also comes in several forms. Direct glare occurs when an unshielded light source shines into the eye from the front, side, or overhead position (this last is known as overhead glare); reflected glare occurs when excess light reflects off a task surface, either as a diffuse veil ("veiling reflection") or as an identifiable shape.

Uniformity is the ratio of light levels across a specified area (e.g., the desk surface; the field of view). It is usually calculated as a ratio of illuminance or luminance, maximum to minimum .

Organizational Productivity through Lighting Design

Light Levels: Illuminance and Luminance

Illuminance levels must be selected to match occupant tasks, and both the age and visual characteristics of likely occupants, as well as the visual difficulty of the task itself. Small and low-contrast objects require more light for equivalent visibility. More light is also required if occupants are older or have visual problems.

Research: Light Levels

Research at IRC (with support from PWGSC) consistently shows that there is no generic illuminance level. Levels must match task demands and individual preferences. Any single illuminance value is likely to satisfy only half of the occupants.

L.4

Research: Surface Appearance

The brightness of vertical surfaces, as well as horizontal task surfaces, is important for occupant comfort. Ambient light quantity and distribution contribute greatly to the atmosphere of a space. For example, shadowed or dark-coloured walls and ceilings can create a cave-like feeling. Light vertical surfaces create a perceptually bright, pleasant atmosphere. To achieve satisfactorily bright vertical surfaces, wall luminance should be greater than 30 cd/m^2.

L.5

Dark surfaces can make an unpleasant space. Note the scalloped shadows at the top of the back wall and the darkness under the shelving.

Organizations like the Illuminating Engineering Society of North America (IESNA) and the Canada Occupational Health and Safety Regulations (COHSR) have established illuminance ranges for basic office tasks. Providing light within these ranges together with some individual adjustability should satisfy occupant lighting needs for safety, health, and task visibility.

More information about these organizations and their recommendations is available at: www.iesna.org and http://laws.justice.gc.ca.

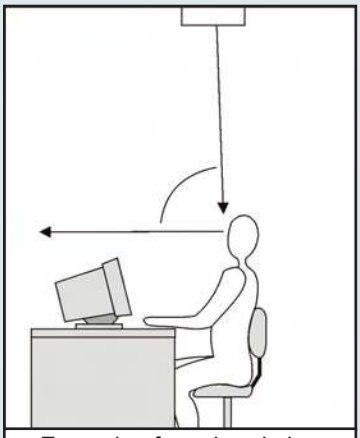
Below are summarized the recommendations from IESNA, COHSR, and IRC for open-plan offices in which computers are used. IESNA recommendations are American National Standards Institute (ANSI) standards. COHSR values are requirements in Canadian federally-regulated workplaces. IRC recommendations are derived from observations during research. L.6

ILLUMINANCE RECOMMENDATIONS		
	Ambient Illuminance -Areas in which simple visual tasks are done.	**Task Illuminance** -Task areas in which complex visual tasks are done using computers.
Illuminating Engineering Society of North America (IESNA)	100 lux (horizontal illuminance) 30 lux (vertical illuminance)	Intense computer use: 300 lux (horizontal) 50 lux (vertical) Intermittent computer use: 500 lux (horizontal) 50 lux (vertical)
Canada Occupational Health and Safety Regulations (COHSR)	300 lux minimum (horizontal)	Intense computer use: 750 lux maximum Intermittent computer use: 500 lux maximum All documents: 500 lux minimum
IRC Research		Intense computer use: 400-500 lux (horizontal) 200-300 lux (vertical)

Glare

Glare is a significant issue in open-plan offices since discomfort and disability glare can affect employee satisfaction and task performance. Glare sources should be identified and glare prevention methods should be introduced. Office designers should consider light sources, location, occupants, task surfaces, and task location.

Direct Glare Sources: In open-plan offices, distant luminaires or lamps can be direct glare sources, as can local, unshaded luminaires. Distant lamps can be visible because there are no full-height walls to block these from occupants' sight lines. Bright sunlight shining through windows can also cause direct glare.



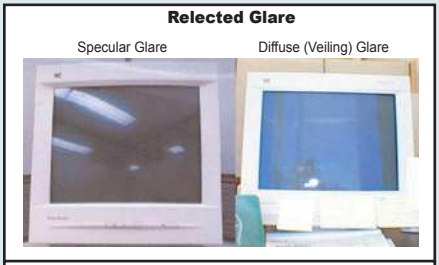
Example of overhead glare

Research: Overhead Glare

Until recently, the offending zone for direct glare was considered to be in the horizontal line of sight, up to 55 degrees above. New findings suggest that luminaires from 55° to directly overhead can cause discomfort if they are too bright. Some parabolic-louvred luminaires can produce luminances high enough.

L.7

Reflected Glare Sources:
Computer screens, polished desk surfaces, or glossy pages are particularly subject to reflected glare, which obscures the image or text on the surface.

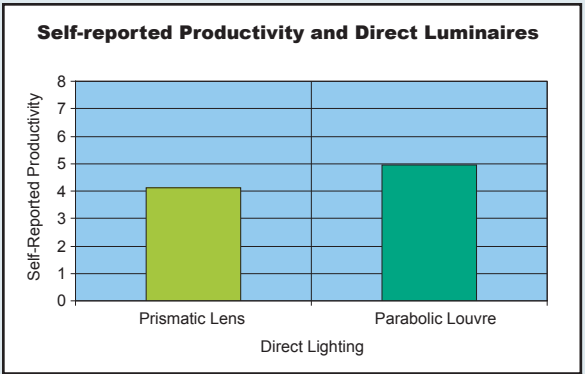


Glare obscures the images on the screen.

Research: Reflected Glare

Most office workers report experiencing glare. According to a Steelcase survey, as many as 80% reported glare problems at least sometimes. Lighting conditions that produce reflected glare on computer screens reduce the ability to work by impairing screen visibility. In one IRC laboratory study, people reported wanting to dim down or turn off a luminaire that was reflected in the computer screen.

L.8



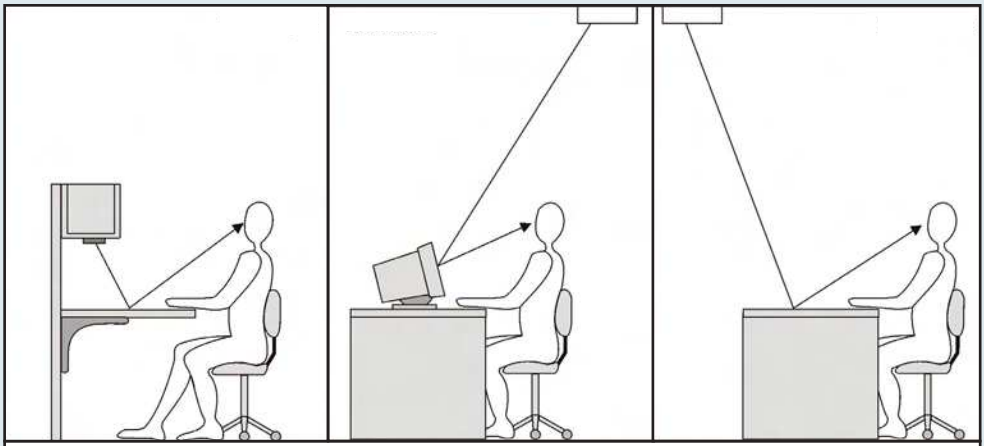
Self-reported productivity was better with parabolic-louvred luminaires. Researchers attributed the better productivity to reduced glare. Based on: Veitch & Newsham (1998).

Many techniques contribute to glare prevention. Office designers should consider the light sources, location, occupants, task surfaces and task location.

Surface Selections: Glossy surfaces should be avoided to prevent glare. This includes furnishings, such as desktops, equipment (particularly computer screens), and also paint. If possible, matte computer screens, flat screens, or attachable anti-glare screens should be used.

Source/task/eye Geometry: This term refers to the relationship between the occupant's eyes, the task he or she is viewing, and the light source. This relationship, if well designed, can reduce or eliminate glare problems. Occupants should not be able to see light sources such as exposed lamps or direct sunlight when in the most common working positions, nor should light sources reflect in task materials or furnishings. Computer use can present a particular difficulty because occupants work upright, instead of looking down at a desk. Distant light sources across the office can cause discomfort for the heads-up view that they would not for a horizontal task location. Each office situation presents a unique challenge; however, shielding light sources and placing occupants and tasks perpendicular to light sources are effective methods.

Source/task/eye geometry problem: The task lamp in this photo causes glare for the occupant looking at papers beside the computer. The occupant has created a makeshift shield to reduce the glare.



These diagrams illustrate problematic source/task/eye geometry. These occupants experience reflected glare.

Uniformity

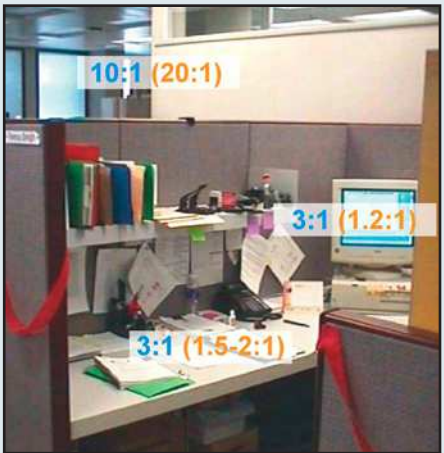
Uniformity ratios establish the difference in light levels that should occur throughout a space. Very high non-uniformity (or high contrast ratio) requires frequent eye adaptation and can increase fatigue and discomfort. Extreme uniformity creates a perceptually flat, uninteresting scene, which is also displeasing. The IESNA Handbook recommendations for uniformity reflect practitioner consensus. IRC recommendations were derived from observations during laboratory experiments.

Research: Uniformity

Occupant surveys and studies show that people prefer some non-uniformity in ambient lighting throughout the office environment because it creates visual interest. On the other hand, uniformity on task surfaces is necessary and desirable. Shadowing or inconsistent light distribution on tasks can be distracting and counterproductive.

L.9

IESNA and IRC UNIFORMITY RECOMMENDATIONS	
3:1	between paper tasks on desktop and adjacent surroundings or vice versa. (IRC research: 1.5 - 2:1)
3:1	between computer screens and adjacent surroundings or vice versa. (IRC research : 1.2:1)
10:1	between near and remote surfaces or vice versa. (IRC research: 20:1)



Uniformity ratios in office space.

Electric Lighting

The ideal lighting equipment is that which will distribute light appropriately given the target lighting design, the interior design, and aesthetic intent. The luminaires should meet these needs when they are installed, and also throughout their service life. The strategy of splitting general-ambient and task-specific lighting achieves most design goals for occupants and addresses energy efficiency.

Ambient Lighting: There are a number of luminaire systems that provide ambient lighting. When choosing a system, designers should keep the following in mind.

Prismatic-lensed (direct) Luminaires are not recommended for open-plan offices because of glare issues. Prismatic lenses light room surfaces well, however, and are good for ambient lighting in areas where glare is not an issue (corridors, lunch rooms, etc.).

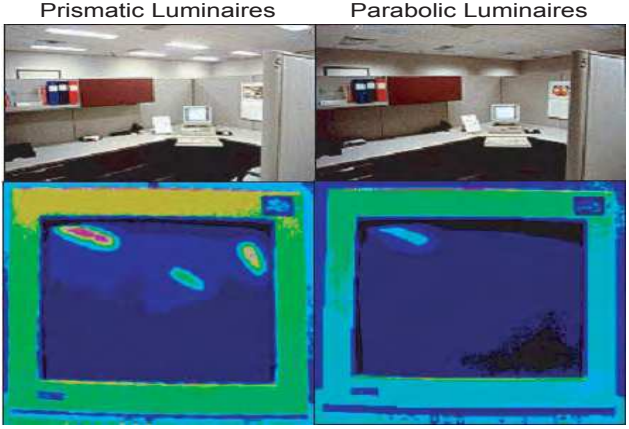
Research: Direct Lighting

A number of studies indicate that prismatic-lensed luminaires can be problematic in open-plan offices because they cause direct and reflected glare. Parabolic-louvred luminaires significantly reduce glare, but can create dark ceilings and walls, which can be displeasing.

L.10

Parabolic-louvred (direct) Luminaires direct light onto the horizontal plane, preventing reflected glare in computer monitors and providing desktop illuminance; however, they do not light walls and ceilings well. Accent lighting or wall washers may be required to create a brighter overall environment. If located directly overhead, parabolic louvres can cause discomfort.

Glare in the Computer Screen: Direct Luminaires



Both direct and reflected glare are much reduced by parabolic-louvred luminaires. Reduced glare can improve occupants' task performance.

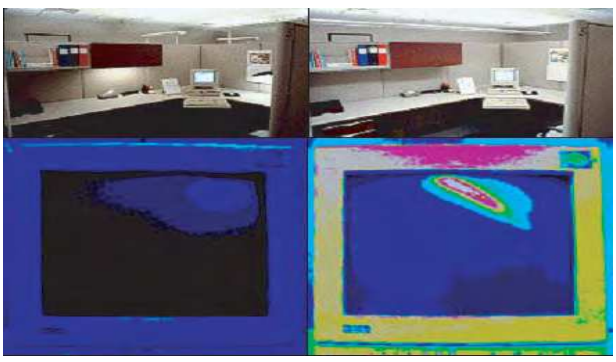
Indirect or direct/indirect luminaires can provide more uniform light distribution, cause fewer glare problems, and illuminate ceilings and walls. They create the perception of a brighter, more open space. However, poor design can make the ceiling a glare source. Fully indirect systems can also give a flat, shadowless appearance. A direct component ensures a level of light and shadow that facilitates depth perception and provides task lighting.

Research:
Indirect Lighting

Indirect or direct/indirect luminaires can reduce glare, tired-eye complaints, and focussing problems. Veitch and Newsham found that occupants prefer approximately 40% indirect lighting in the office. Houser et al. found that judged spaciousness increased with the proportion of indirect light and that the most preferred conditions had more than 60% indirect light.

L.11

Glare in the Computer Screen: Direct/Indirect Luminaires



Direct/indirect luminaires can reduce glare, but can create major problems if improperly designed or located.

Accent Lighting: Accent lighting can be used to fill shadows and create visual rhythm and interest. Unpleasant shadows can occur at wall-ceiling junctures or can be created by furniture and shelving units. Accent lighting can eliminate the unpleasant shadowing.

The accent lighting, on the left wall, cnetre table and back wall, contributes to the aesthetic look and general illumination. From: Boyce et al. (2003). Courtesy of the Light Right Consortium. L.12

Task Lighting: Task lighting provides both high illuminance on task surfaces that require it (i.e. paper tasks) and occupant control. Task lighting can also fill shadows caused by shelving units. Under-shelf, partition, and desktop lighting should be considered.

Only the task lights are on in this photo, showing how task surfaces can be highlighted with local, high illuminances. An under-shelf luminaire and an adjustable desktop luminaire have been used.

Research: Task/Ambient Lighting

The practice of combining lower ambient light levels with targeted task lighting developed as an energy-saving technique. Initially, there was concern that the resulting non-uniform light levels across desks would reduce performance; however, studies have not identified problems. IRC research found that people gave higher ratings of lighting quality and satisfaction to an open-plan office with task/ambient lighting than to lighting systems that did not use task lighting.

L.13

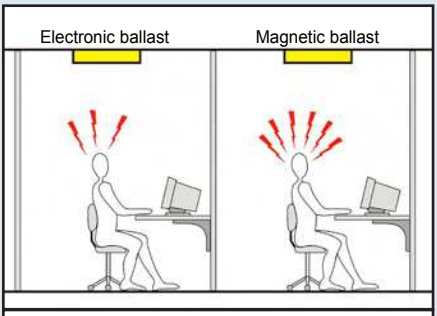
Lamps: Fluorescent or Compact Fluorescent Lamps (CFL) are recommended for offices by lighting professionals because they are more energy efficient than incandescent sources. Incandescent lamps (including halogen) are inappropriate for general lighting because their low efficiency adds unnecessary heat and requires additional cooling to compensate. Fluorescent lamps come in a range of colour temperatures that allow the lighting designer to choose lamps that are most effective for the space, colours, and amount of daylight. If colour discrimination is important in an occupant task, then the colour rendering properties of the lamp must be considered. Lamps with a Colour Rendering Index (CRI) of 90 or greater are recommended for colour identification and matching. A CRI of 70 or 80 is adequate for most office settings.

Research: Lamp Type

Some manufacturers of lamps and fluorescent lamp filters claim to have products that mimic daylight, but no single source can replace the variability of daylight. Moreover, claims that any particular fluorescent lamp improves health, performance, or comfort do not stand up to scrutiny using reliable scientific methods. The only exception concerns colour discrimination; if fine distinctions in colour are necessary for tasks, any lamp with a high colour rendering index (CRI) will improve task performance.

L.14

Ballasts: A ballast is a device that controls and modifies the electricity supply that operates fluorescent lamps. Electronic ballasts are recommended instead of magnetic ballasts.



Headaches are twice as frequent with low-frequency magnetic ballasts. Based on: Wilkins et al. (1989).

Research: Ballasts

Flicker occurs because light from fluorescent lamps with magnetic ballasts oscillates at 2 times the rate of the AC electric supply. This effect can increase headaches and eye-strain. Studies show that high-frequency electronic ballasts eliminate perceptible flicker, and, therefore, can improve visual comfort, reading performance, and computer-based work.

L.15

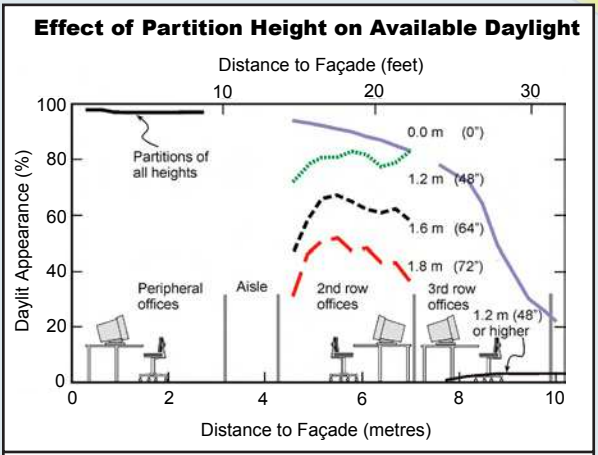
Daylight Design

Building architecture largely determines the extent to which daylight can contribute to office lighting, but interior design choices influence its usefulness. Controlled daylight makes the office look more pleasing and also saves electric energy.

Research: Preference for Daylight

Daylight is important because people spend so much time indoors. Office occupants prefer some daylight and believe it makes them healthier and more productive. The effect of windows and daylight on improved satisfaction was among the strongest findings from the COPE field study.

L.16



Partition height affects available daylight in 2nd row workstations. From: Reinhart (2002).

Useful daylight reaches around two workstations deep (3rd row workstations get useful daylight only without partitions). Therefore, daylight should be considered for the first two rows and then supplemented with electric light to meet illuminance and uniformity requirements.

While daylight is desirable, direct sun causes discomfort and requires control. Blinds, shades, and other controls can be occupant-controlled or automatic. If they are automatic, manual over-ride must also be possible.

Daylight penetration should also be maximized through room and workstation characteristics. Reflective ceilings, and windows that meet the ceiling can increase daylight penetration. In terms of the workstation, partitions near windows should be lower, or mounted with transparent tops, to allow more daylight to penetrate further into the office (so long as the design does not compromise visual privacy and acoustic conditions). High partitions and tall shelving units should also be placed perpendicular to windows so that they do not block light. Creative workplace design and partition layout can limit glare for occupants while still maximizing daylight penetration. To help designers make good use of daylight, Lawrence Berkley National Laboratory (LBNL) has written an excellent guide to daylighting, which PWGSC has adapted and updated for the Canadian climate. IRC has developed software tools to assist with daylighting design. L.17

Smart daylight design: The transparent tops of the partitions allow daylight to penetrate into the rest of the office. The blinds allow occupants to avoid glare if it becomes a problem.

Office Design

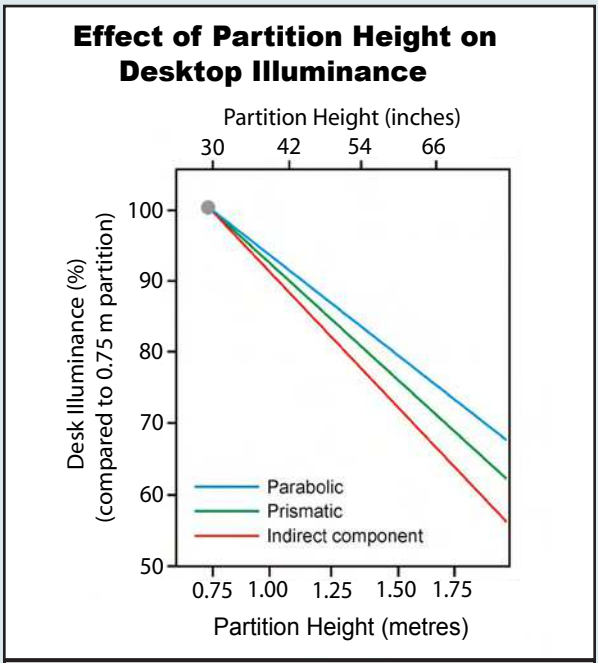
The modular furniture, partitions, office layout, and the small area of cubicles can create design challenges. Lighting and workstation design should proceed concurrently so that desired illuminance is achieved and also so that other office conditions, such as good acoustics or indoor air quality, are not compromised by design decisions.

Luminaire Spacing, Placement, and Number: Luminaire layout relative to the workstations largely determines light distribution in the office. Manufacturers provide guidance for their products, but these guidelines assume an unobstructed space. Furnishings, partitions, and source/task/eye geometry must be considered during luminaire layout.

Acoustic conditions must also be considered because luminaire placement affects the way in which luminaires reflect sound between workstations.

Ceiling Characteristics: Ceiling reflectance is especially important for daylight and indirect light distribution. Recommended ceiling reflectances are between 75% and 90%; recommended wall reflectances are between 40% and 70%. With indirect lighting systems (especially with T5 lamps), spots on the ceiling above the luminaires can become too bright; appropriate suspension distances for the luminaires should be used to prevent this problem. L.18

Partition Characteristics: Partition height and colour are important determinants of the achieved illuminances and luminances in the furnished space. Partition height, for example, influences the amount of light reaching the desktop. Lower partitions prevent unwanted shadows, but have an effect on acoustic and visual privacy. Luminaire spacing should be designed around the chosen partition height. Light partition colours are also particularly necessary to the success of indirect or direct/indirect installations. L.19



Partitions reduce the amount of light that reaches the desktop. Each type of luminaire is also affected to a different extent. Open-plan office lighting needs to be designed carefully in a furnished room. From: Newsham & Sander (2002).

Office Colours: Light colours for furniture elements contribute to better light distribution. However, colour should not be eliminated from the office. Colourless, bland offices are unpleasant and boring. Consider using light colours for large areas, such as partitions, with stronger or darker accents to provide visual interest.

Individual Controls

Controls such as dimmers, task lighting, and window blinds give occupants the ability to satisfy their personal preferences and to modify the lighting conditions as their tasks and lighting needs change. For controls to be effective, however, they have to be accessible so that they do not take a lot of time to adjust.

Controls interface: The PWGSC-developed lighting controls on this computer interface allow users to set the brightness of their workstation lights; it also allows them to set on/off timers for their workstation lighting.

Research: The Benefit of Controls

Personal lighting control can improve environmental satisfaction and self-rated task performance. Personal controls also allow occupants to satisfy their own needs and preferences without encroaching on their neighbours. This set-up can create a pleasant mood, which can improve conflict resolution and cognitive performance.

L.20

Research: Keep Controls Simple

Researchers have found that too many controls or complicated controls can become stressful because people want to focus attention on their work rather than on learning environmental controls.

L.21

COPE-ODE

The COPE Office Design Evaluator allows designers to predict the effects of lighting design on lighting conditions and occupant satisfaction. Users can set their office characteristics and read suggestions for improving the design.
Available at: http://irc.nrc.gc.ca/ie/cope/07.html

Workstation Design and Layout

Practical Tips: DO . . .

Furnish cubicles based on occupant job needs;
Provide visual and acoustic privacy with enclosure (higher number of partitions, and larger workstations);
Provide adjustable furnishings and environmental controls;
Provide lockable storage for personal items;
Locate work groups in the same area;
Provide access to a window and a view;
Match alternative office strategies to tasks and employee needs.

Practical Tips: DO NOT . . .

Crowd occupants;
Make shared resources difficult to access or place routes through work groups;
Place workers in busy, noisy areas of the office;
Prevent personalization of the workstation.

A workstation

The Workstation

The Function of the Workstation

Offices exist primarily to allow employees to do their work, and, thereby, support their organization's goals. Though work performance is the key function, a workstation should also provide a supportive environment for mental and physical well-being. Employees may spend upwards of 30% of their waking hours per year in their offices, which need to be comfortable and satisfactory.

Possible workstation set-ups

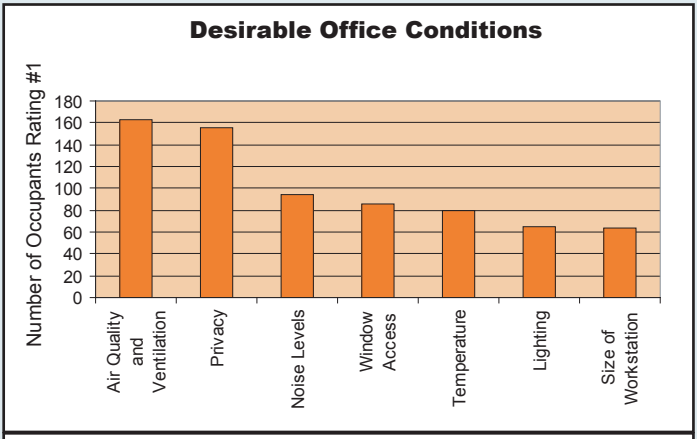
Like all offices, open-plan office workstations must provide the space, equipment, and conditions that employees need to do their work. To meet the functional requirements of each job, one needs to know who will work in the office and the variety of tasks that they will do.

The other major consideration should be the individual and his or her specific needs and preferences. It is not always possible to consult with each individual, but making allowances for preferences and allowing some adjustability can satisfy people's differing needs. The employees are the most significant determinant for all successful design choices.

Desired Office Conditions

Asking employees is the best way to identify task needs and preferred conditions. In the COPE field study, researchers surveyed over 700 open-plan office occupants about their opinions of physical conditions. The participants rank-ordered the importance of seven features. Air quality and ventilation

were most frequently ranked number one in importance; privacy was the second, and noise levels, the third.



These office conditions were ranked 'Most important' of seven physical conditions. From: Veitch et al. (2003).

The ways that office design affects acoustics and noise, indoor air quality and thermal comfort, and lighting conditions have been discussed; however, there are some other major needs that are important to employees. Privacy and window access, which were second and fourth most frequently ranked number one, are greatly affected by the design of the workstation. Task needs, personalization, and adjustability are also important considerations when choosing the furnishings, equipment, space, and layout. When these needs are not addressed, employers risk unsupportive workstations and dissatisfied employees. W.1

Meeting Employee Needs with Good Design

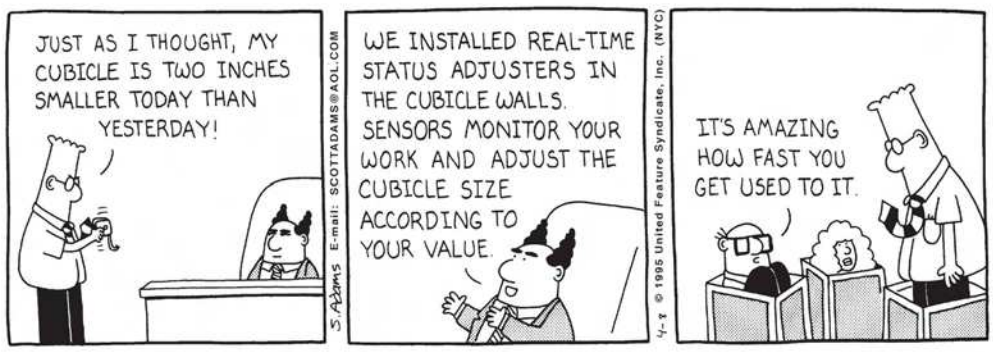
Designing good workstations requires an awareness of employee behaviours and responses to workplaces and physical conditions. Most research to date has focused on employees in traditional open-plan office designs, from bullpens with no dividing partitions to cubicle enclosures. Recommendations based on these research findings will help designers create workstations that allow employees to complete their work in comfort and enable organizations to meet their goals.

Bullpen-style open-plan office

Novel forms of working, such as team spaces, and 'hot-desks', have not yet received much research attention. Nonetheless, the same principles apply to the design of any office: consider the employees.

Traditional cubicle open-plan office

Employers can communicate respect to their employees by showing sensitivity to their needs or can reduce morale unwittingly with poorly considered or arbitrary design choices. Many of the office cubicle jokes in the Dilbert™ cartoons play on this relationship, as well as on the unsatisfactory physical conditions in the workstation. W.2



DILBERT™ reprinted by permission of United Feature Syndicate, Inc.

The starting point for all office design is an understanding of the job functions and the specific individuals who will work in the space.

Organizational Productivity through Workstation Design and Layout

Privacy and Social Interaction

Privacy is one of the most important functional requirements of an office. Having privacy means both freedom from distractions and the ability to prevent others from obtaining knowledge about oneself and one's work.

Distractions from others principally involve sounds, especially overheard conversation. However, visual distractions may also present problems if there is a lot of pedestrian traffic past the workstation.

Research: Distraction

Freedom from distraction is essential since more than 80% of most office workers' time is spent on quiet work or computer work. This explains why freedom from distraction is among the most desired open-plan office conditions. Even team work requires distraction-free spaces; most team members' time is spent on a mixture of group meetings to decide on courses of action, and individual quiet work on the resulting tasks. Impromptu meetings and telephone conversations also benefit from being in quiet conditions without outside interference.

W.3

Nevertheless, contact between workers cannot and should not be eliminated in an open-plan office. The workplace must strike a balance between the need for solitude for concentration and the need for contact with co-workers. Consulting and meeting with colleagues is necessary to most job functions, and social interaction builds social support. Communication and social support are strong contributors to healthy workplaces and lowered absenteeism. People who have supportive relationships with co-workers are better able to cope with stressful conditions. W.4

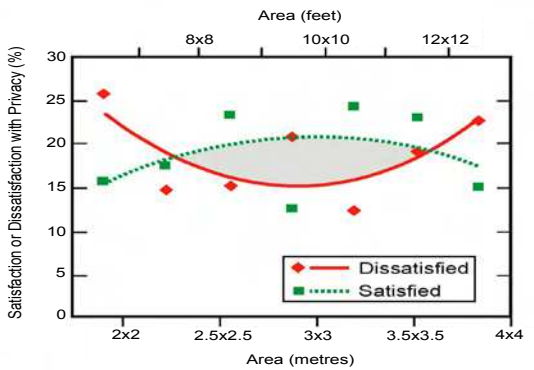
Workstation Boundaries

Complaints about privacy and distraction revolve around workstation boundaries: spaces that are too small; partitions that are too low; layouts that produce too much traffic. These all contribute to low satisfaction and poor conditions.

Workstation Size: Small workstations place people and noise sources closer together, compromising privacy. Large workstations result in long distances to shared resources and may increase social isolation. COPE research recommends workstation sizes between approximately 5.9 m^2 and 13.4 m^2 (64 ft^2 - 144 ft^2). W.5

Research: Workstation Size

Studies that compare the effects of smaller and larger workstations have found that larger workstations are associated with higher environmental satisfaction, job satisfaction, and perceived privacy. During the COPE project, researchers found that more occupants were satisfied than dissatisfied with privacy when workstations were neither too small nor too large. Small workstations also lack storage and surface space, which can directly impede the work process. W.6



COPE field studies found that more occupants are satisfied with privacy when workstations are neither too large nor too small. From: Newsham et al. (2003).

Enclosure: Satisfaction with privacy is affected by the physical enclosure provided by the number, height, and characteristics of the partitions.

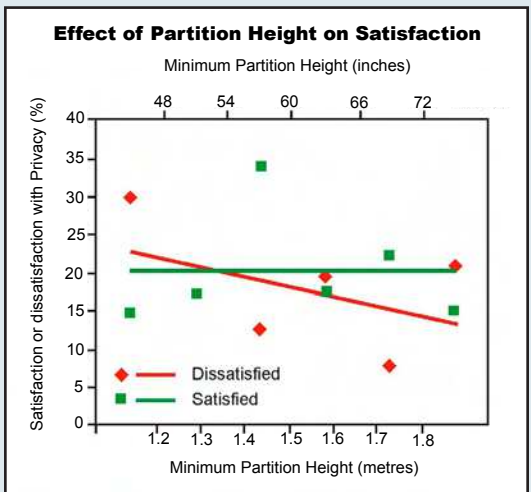
Research: Enclosure

Research has found that general communication increases with fewer barriers, but work-related, communication does not. Having few barriers can increase dissatisfaction with privacy. A study by BOSTI found that increased enclosure was associated with higher self-rated job performance, and COPE research found that partition height affected satisfaction with privacy.

W.7

Most people prefer the visual privacy that comes from opaque partitions on all four sides of the workstation. There are some circumstances in which a fully open, bullpen arrangement is suitable. Some theorists believe that a fully open arrangement will increase communication and collaboration, but research corroboration of this belief is lacking.

Partition height also contributes to enclosure. The COPE field study found that partitions higher than approximately 1.4 m (54 in.) increase satisfaction with privacy, probably because seated neighbours cannot see over into others' workstations; heights more than 1.6 m (64 in.) are required for acoustic privacy (see Acoustics). Lower partitions do allow deeper daylight penetration. Therefore, employee needs and preferences should be considered when making the choice between low and high partitions. W.8



The number of dissatisfied occupants was greater than the number of satisfied occupants with shorter partitions. From: Newsham et al. (2003).

These two workstations are very exposed to the corridor and to neighbouring workstations. Occupants are likely to be distracted by traffic and neighbours' conversations and they have very little sense of enclosure. There is no acoustic or visual privacy in this arrangement.

Layout: Work-related communication and privacy are affected by the number and arrangement of workstations. To influence functionality and satisfaction, successful workstations should be designed around work groups, shared resources, and the flow of occupants through the office.

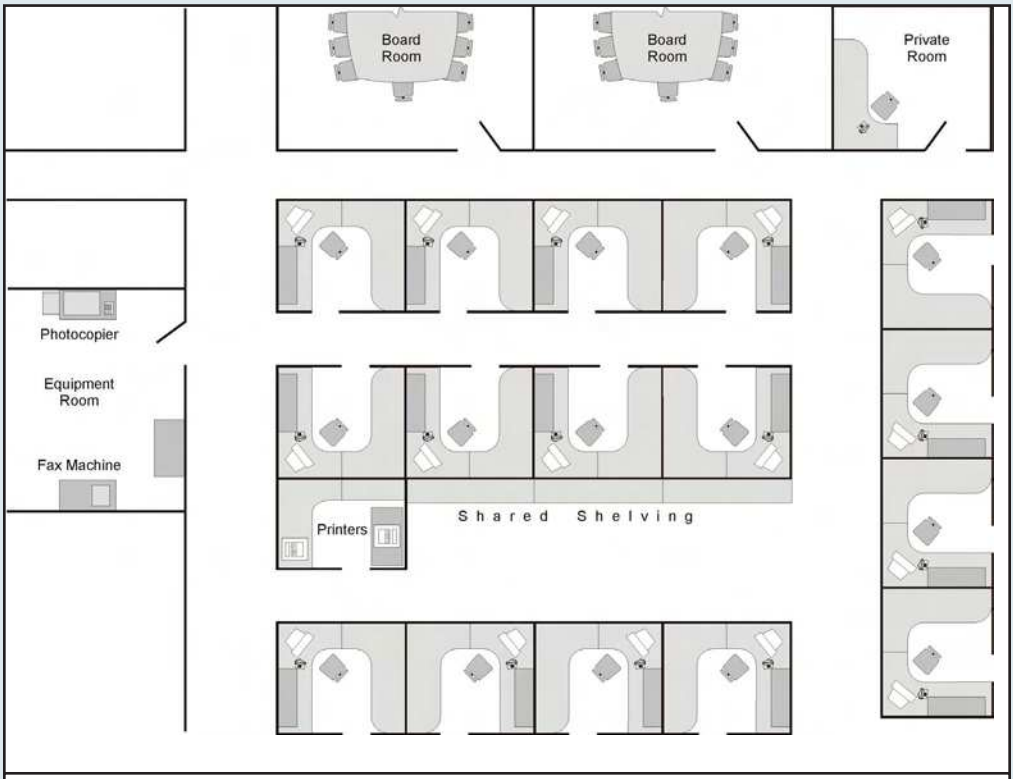
To satisfy privacy and density conditions, the number of people in a space should be limited based on the size of the space. Of the people in the office, groups that work together on shared goals should be located together, reducing the time spent looking for shared resources and arranging discussions. Grouping colleagues also facilitates informal communication, especially if there are shared spaces for social interaction (break rooms, meeting rooms). A rule of thumb for group arrangements states that members should not have to walk more than 10 m (30 ft) to reach shared resources, including colleagues and supervisors.

Efficient workstation layouts have clear paths so that way-finding is easy and so that distraction from passers-by is minimized. Ideally, work group areas should have their own boundaries, which help develop a shared social identity and limit distraction.

Research:
Social Density

The presence of other people can be a stressor. As the number of people per room (social density) increases, environmental satisfaction decreases. More people means greater distraction sources, as well as more relationships to maintain. With high environmental control, occupant-rated productivity was best in offices with 5-9 people. Other researchers also found that task performance dropped as the number of people in the office increased.

W.9



There are many issues to be considered in office layout: visual and acoustic privacy, access to resources and a window, workstation size, and density.

Window Access: As many workstations as possible should have window access, direct or distant. Corridors can be placed next to window walls, or cubicle designs with some low partitions can be considered to provide distant window access. Windows can also be provided in lunch and meeting rooms.

Research:
Windows

Access to a view of the outside, particularly a nature view, helps to improve well-being. Several studies have found that hospital patients with window rooms recover from surgery more quickly and require less pain medication than those in windowless rooms. Office workers also benefit from windows. In a study of a Mediterranean organization, office workers whose rooms had greater sunlight penetration showed greater job satisfaction and improved overall well-being. Those occupants with a nature view had lower intention to quit.

W.10

These workstations have been set at an angle to the facade with low partitions perpendicular to the windows so that everyone in the office has access to the view and to some daylight. (Acoustic privacy is less here, but the occupants have chosen daylight and view over speech privacy.)

Workstation Furnishings

Each job and task function and comfort need has specific furnishing requirements. For example, architects require sufficient space to lay out building plans. Graphic designers may require more than one computer monitor, space for them, or a place for a specialized input device like a tablet. There is no substitute for knowing the particular needs of the occupants, and there is no generic one-size-fits-all design solution. However, general principles can guide specific choices.

As well as task needs, furnishings affect the health and comfort of occupants and the aesthetic appeal of the office.

Research: Furnishings

Occupants notice and care about the aesthetics of the workplace. The messages they infer about their status in the organization influence morale, and employees look for furnishings that are appropriate to their rank and value. The quality, durability, attractiveness, and newness of furnishings positively influences comfort and general satisfaction with the office environment. Buildings with better maintenance of elevators, rest rooms, office equipment, etc. show higher environmental satisfaction, comfort, and health among occupants.

W.11

Surfaces and Storage: Even though workstation surfaces have shrunk with shrinking workstations, the need for surfaces to spread work out and to store work has not diminished. Paper consumption in U.S. offices reportedly increases approximately 20% annually, and office occupants require space in which to process all this paper. BOSTI found that workers needed two work surfaces and three to five file drawers, though some employees may need more. At least some of the storage should be lockable to provide a secure places to store valuable items. W.12

The cluttered nature of this workstation suggests that the occupants' space, surface, and storage needs are not met.

Seating and Posture: Good office furnishings should meet standards for ergonomics, such as those of the Canadian Standards Association, to ensure comfort and health. The choice of chair and the layout of the workstation surfaces should provide support for the lower back, wrists, and arms, and should prevent the neck from being tilted far forward or back to view the computer monitor. Some employees may require customized solutions to accommodate their individual dimensions. Manufacturers provide a range of sizes both larger and smaller than the usual design range. W.13

Research:
Musculo-skeletal Pain

The human body is adaptable, but it has limits. Workstation set-ups that fail to support the body, or that require unnecessary repetitive motions, can cause pain and disability. These conditions are exacerbated by relentless job demands and a lack of social support at work. Fully-adjustable chairs that are appropriate to the individual's size contribute to reducing musculo-skeletal symptoms. Comfortable, adjustable chairs and training on their use given in a tax-processing agency created sufficient savings to pay for the expenditure in a few months. Job design also contributes to musculo-skeletal pain, and increasing the frequency of short rest breaks can reduce pain. W.14

Personal Control

Providing control over the furnishings and conditions allows occupants to help designers identify key task needs and allows them to adjust the conditions to satisfy changing preferences throughout the day.

Adjustability: Humans differ from one another in every physical dimension. Because one size does not fit all, furniture must be adjustable in order to set the heights of surfaces and seats at levels suitable for proper posture. Adjustability also ensures that occupants can change their positions throughout the day to avoid fatigue.

Research: Adjustability

Environmental satisfaction and physical comfort are higher for employees with adjustable furniture. Adjustability enables workers to change settings to fit their dimensions and task needs, reduces the risk of musculo-skeletal disorders and promotes work performance. Similarly, adjustable personal controls are associated with improved self-rated productivity, comfort, and health. However, controls do not guarantee a good outcome. Adjustable features must be desirable to the occupants, easy to use, and effective; otherwise they become frustrating or are an expense with no employee benefit.

W.15

Similarly, individual preferences for physical conditions differ. Control over elements of the physical environment (lighting, air movement, temperature, and acoustics) allows individuals to adjust levels to their choice. These controls may be as simple as a manually operated Venetian window blind, or as sophisticated as personal air supply controlled on the occupant's computer. In addition to employee benefits, research shows that personal controls can result in energy savings because many people prefer levels lower than the fixed settings. W.16

Controls interface: These lighting and temperature controls are accessible on users' desktops.

Personalization: Many employees look for means to express themselves through the decoration of their workstations. The workstation design should provide sufficient space, vertical and horizontal, to support personalization through the display of memorabilia, plants, photographs, etc. In addition, organizations should support personalization with policies that permit it and set out reasonable limits, if necessary.

Research: Personalization

The items that occupants display express their identities and contribute to others' impressions of them, thereby playing a role in social relations. Employees who display more personal items in their offices show higher environmental satisfaction, job satisfaction and well-being, and rate their organizations more positively. In addition, organizations that have policies permitting personalization are perceived as healthier.

W.17

This workstation has been greatly personalized: low ambient light levels, task lights, and decoration.

Participatory Design: The best way to get accurate information about job functions, work processes, and specific employee needs is to involve the occupants in the design process. Whenever employees are available for consultation, the designer should take steps to discuss their needs and request

their input. Several consultation techniques are available, including formal surveys and scales for pre- and post-occupancy evaluation, focus groups, and fitting trials (test runs of prototype designs). For large or complex projects, environment-behaviour consultants can lead this process for best efficiency. W.18

Research: Participatory Design

Influence on the design process may increase environmental satisfaction by fulfilling the need to demonstrate environmental competence (the ability to deal with one's surroundings in an effective and stimulating manner). University students who simulated participation in dormitory design reported feeling more creative, responsible, and helpful than students who were told what the new design would be. BOSTI's large field study found that participation in the office design process increased overall satisfaction with the resulting environment and immediately increased job satisfaction. W.19

Alternative Office Strategies

Although the majority of office workers occupy traditional open-plan office workstations, alternative office strategies like team spaces, hot-desks, flexible working hours and telecommuting are becoming more popular. In a recent survey by IFMA, 62% of facility managers reported that the offices they manage use some form of alternative officing. The most common form was team spaces (42% of respondents), followed by telecommuting (22-32% depending on the organisation's size). W.20

Many of the principles and design strategies described in the previous sections are applicable to these alternative office designs. It is still essential to design with employee needs and tasks in mind. Whether employees work in traditional cubicles, at home, or in team spaces, they still need appropriate lighting, thermal, air quality, acoustic, and work space conditions to function effectively. A suitable match between the strategy and the job requirements is key to effective alternative office designs.

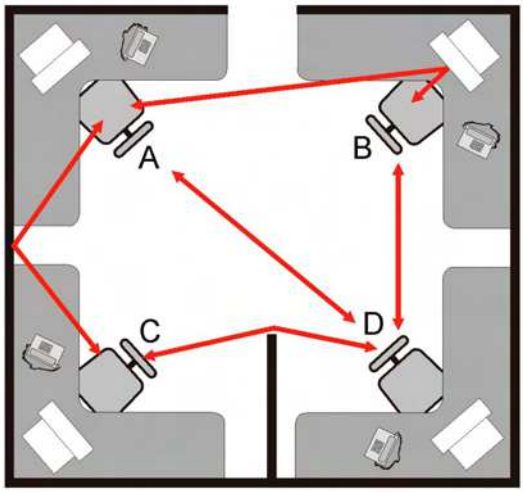
Team Spaces: Good workstation design demands that employees who work together be clustered so that they are not too far away from each other and shared resources. The team space concept is an extension of this principle: a team of employees who work closely together are located in one, larger workstation with high partitions around the team, and smaller (or no) partitions between team members. Team spaces usually include individual workstations for each team member, and an area for collaborative work. This office design is useful for work requiring a high level of collaboration, but can be problematic if group members are primarily engaged in individual tasks that require quiet and concentration.

Research:
Team Spaces

There is anecdotal evidence that team spaces improve team performance, but systematic and comprehensive research is sparse. PWGSC-sponsored IRC research found that achieving acceptable privacy and acoustic conditions can be challenging in team spaces. This is obviously not an issue during collaborative tasks, but could inhibit performance when team members are working separately.

W.21

Care should be taken to ensure team members can work effectively on their individual tasks without unwanted noise disruptions. Locating team members in the corners of the team space, facing outwards, is one way to reduce unwanted noise transmission from speech. Increasing the distance between co-workers can also help. The ceiling and inner surfaces of the team space should be highly absorbent, and additional smaller partitions between team members can also help to reduce sound transmission.



Occupant orientation and small partitions can help improve team spaces for the periods of individual work.

An alternative strategy to using team spaces is providing dedicated rooms that can be used by a team during a project. Sometimes referred to as “war rooms”, these areas are used as a base for the team members and their shared resources and equipment. Often team members move into the space for the duration of the project, but they retain their individual workstations, for tasks requiring concentration and for all work after the project is completed.

Flexible Working Hours: Flexible working arrangements range from relatively informal agreements to 'bend' traditional working hours on occasion, to more formal and permanent agreements such as flexitime and compressed work weeks. A recent survey by Statistics Canada indicated that around 40% of office-based employees work flexible hours.

Research: Flexible Work Hours

Research indicates that flexible work arrangements can have positive effects on job satisfaction, task performance, self-rated productivity and commitment. These effects probably occur because employees experience less conflict between work and family demands, have greater control over their work schedules, and are able to accommodate their preferences. However, it has also been suggested that too much flexibility can be detrimental, as employees lose touch with those working regular hours, and the demarcations between work and non-work times of day become blurred.

W.22

Flexible working hours change the times when employees work, but the office space remains the primary working location. Recommendations for the physical office environment are equally important for flex-workers. Flex-hours can also be seen as a type of adjustability or personal control; employees can choose to take advantage of certain conditions, such as quiet times early or late in the day.

Telecommuting: Telecommuting allows flexible time and location. Telecommuters work from outside the office, either at home or in a telework centre, and "commute" to the office using computer and communications tools. Statistics Canada reported that around 5% of employees use formal telecommuting strategies. Most telecommuters work outside the office an average of five to six days per month, though some work outside the office permanently.

Research: Telecommuting

Research on telecommuting indicates both positive and negative effects on employees. Telework has been associated with higher self-reported task performance, improvements in job satisfaction and commitment, and reduced staff turnover. However, other studies suggest that telecommuting can erode relationships with managers and co-workers, create social and professional isolation, increase work-family conflict, and increase the tendency to overwork. The success of telework programs depends on how they are implemented and supported, and on the frequency that employees work away from the office.

W.23

Employees working at home still need a supportive physical environment, and all the recommendations made previously apply to the telework environment. Managers should ensure that their employees are aware of their home acoustics, lighting, air quality, thermal conditions, and workspace arrangement. In addition, it is important that teleworkers receive the appropriate technology and furnishings to outfit their home offices. For employees who telecommute on a permanent basis, steps should also be taken to ensure that they do not become isolated from co-workers and from opportunities to network and advance their careers.

Hot-desks: Hot-desk strategies, also known as "hotelling" or "free-address" spaces, are used by employees whose jobs require them to spend a large proportion of their time out of the office. Rather than providing a workstation for each individual, organizations create a smaller number of workspaces that can be booked as needed. Each workspace is equipped with a computer, phone, and other necessities, and often includes hook-up points for lap-tops and other personal electronic devices. Personal work materials are kept in moveable units that employees can wheel to their chosen workspace.

Research: Hot-Desks

There is little rigorous research examining the effect of hot-desks on employees. However, anecdotal evidence suggests that employees do not always view them positively. IFMA reported that 27% of facility managers surveyed noticed a reduction in morale after the use of hot-desks.

W.24

Even though hot-desk workers spend less time in the office, their needs, while they are there, are similar to those of employees using traditional workstations. Good office design is therefore just as important for this type of alternative office strategy. Often hot-desk offices are very open, bullpen-style spaces; the assumption is that lack of privacy will not be detrimental because workers are there for relatively little time. However, this environment is often the only place in which hot-desk employees can address focused work because their time away from the office is spent on the road or with clients. Hot-desks also reduce the opportunities for employees to establish a personal territory in the office and personalize their workspaces. Ways should be found to make the hot-desk stations satisfactory for the employees. Adjustability is particularly important because each workstation will be used by a number of different people. It is also a good idea to provide a range of different spaces (individual workstations, quiet areas, meeting rooms, etc.) so that hot-deskers can choose spaces suited to their current tasks. It is also important to include some social areas so that workers who spend little time in the office have the opportunity to meet one another informally.

COPE-ODE Software

No matter the type of workspace, occupants are looking to meet the same comfort and task needs. Designers can use the COPE Office Design Evaluator to model sample environments and the resulting conditions. The software can also alert designers to potential problems and identify the good features of the design. As well as the practical recommendations mentioned in this guide or provided by the software policies encouraging communication between employees and management, feedback on office design, and participatory design should be part of any office design strategy. Open discussions between management, designers, and employees will ensure that employees are best satisfied with their work arrangements.

Available at: http://irc.nrc-cnrc.gc.ca/ie/cope/07.html

Conclusion
The Bottom Line

Influencing organizational productivity is a very complex undertaking because there are so many variables that play a role in the input/output relationships. Given that it is also difficult to scientifically measure the role of any one of the elements that contribute to productivity, how can any recommendation be guaranteed to produce exact results?

Our focus is on employee behaviours and attitudes that factor into the productivity equation. As we have discussed, employees are the largest expenditure in an organization; they also have the greatest and most direct effect on the products created or services delivered. With direct measurements of how workplace design affects employees, researchers can make meaningful recommendations for improvements that will enhance employee contributions to the bottom line: productivity.

Through research, it has become clear that improvements to the office can influence employee satisfaction, commitment, task performance, health, and comfort. These employee outcomes are essential to an organization's success; therefore, the environment's importance cannot be ignored or down played. The time and effort spent on improving offices represents a small percentage of an organization's costs and is an investment that will benefit the organization's greatest asset: its employees.

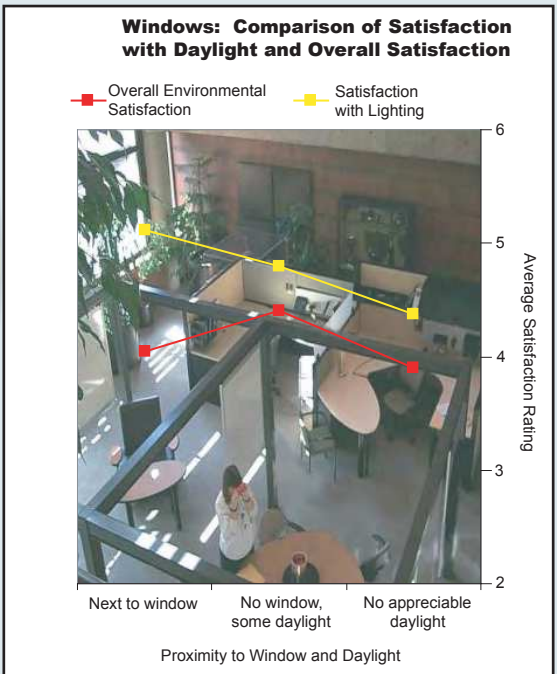
Complete Summary of Recommendations

The most important recommendation: design for the occupants and the tasks that they do. However, priorities must be selected during the design process; office features that satisfy needs in one dimension sometimes conflict with goals in other dimensions. Designers need to be aware of this fact so that they can focus on the key factors of the office and implement a successful design. The COPE-ODE and COPE Calc software can help designers make supportive office choices: http://irc.nrc-cnrc.gc.ca/ie/cope/07.html

Research: Design Interaction

Research-based recommendations sometimes conflict, making it necessary to prioritize satisfaction goals. Partitions should be low to allow daylight access; however, low partitions are problematic for good acoustic conditions. Occupants close to windows are more satisfied with lighting, but less satisfied with thermal comfort, and are less satisfied overall. Office designers need to rank occupant needs and make decisions about which needs will be met by the design. Occupant input is the best way to determine the important features in a given project.

C.1



Proximity to a window increases satisfaction with lighting, but can decrease overall satisfaction. This is probably because windows can create thermal discomfort from undesirable local heat or cold. Based on: Veitch et al. (2003).

The recommendations discussed in this guide have been summarized by office element.

Partitions:

-Partitions that enclose occupants on at least 3 sides;
-Opaque for visual privacy;
-Sound Transmission Class (STC) of at least 20;
-Sound Absorption Average (SAA) of 0.70;
-Light reflectance of 40-70%;
-Aesthetically pleasing: shape, colour, texture;
-Heights of at least 1.4 m, (54 in.) for visual privacy; heights of at least 1.6 m (64 in.) for acoustic privacy; maximum height of 1.7 m (66 in.) for perception of indoor air quality (IAQ);
-Balanced privacy and light distribution and daylight access; transparent tops for daylight penetration;
-Low contaminant emission.

Walls:

-Reflectance of 50-70% for light distribution;
-Coverings with SAA of 0.7 for privacy (where possible);
-Paint with low contaminant emissions.

Workstation:

-Sizes that provide adequate space for employee tasks, comfort, and personalization; consider a minimum of approximately 5.9 m^2 (64 ft^2) and a maximum of 13.4 m^2 (144 ft^2); avoid high density (many people in a space or very small spaces);
-Isolated from noise and air pollution sources such as equipment, main corridors, lunch/meeting rooms, etc.;
-Located near important resources such as team members and equipment; balanced needs for resources, privacy, and IAQ;
-Temperatures between 20 and 28°C (68-82°F), depending on season and relative humidity;
-Relative humidity between 30% and 60%;
-Air velocity below 0.2 m/s (40 fpm) unless personal control is provided;
-Regular cleaning and maintenance.

Furnishings and Equipment:

-Based on occupant needs and tasks: a computer, more than one work surface, a comfortable chair, lockable storage space, and some shelving are minimum requirements;
-Adjustable furnishings that can be modified to fit personal preferences and characteristics (height, leg length, reach); this includes chairs, surface heights, shelving, etc.;
-A desk-chair arrangement in which the most common task position is glare-free and has appropriate lighting (source/task/eye geometry), and visual and acoustic privacy;
-Placement that will not subject occupants to local thermal discomfort from draught or radiant heat/cold;
-Low contaminant emission;
-Non-glossy surfaces: desks, computer screens, equipment, shelving, etc.; consider attachable anti-glare screens for computers;
-Light colours for better light distribution and atmosphere; avoid blandly colourless offices.

Ceiling:

-Light reflectance of 75-90%; ensure that the ceiling does not become a glare source;
-SAA of at least 0.90; consider baffling and other ceiling designs that will reduce sound travel;
-Paint and material with low contaminant emission.

Windows:

-As many as possible to increase daylight;
-Upper window limits that are as close to the ceiling as possible to maximize daylight penetration;
-Either direct or distant access to windows for all occupants (in the workstation or meeting/lunch rooms);
-Shading devices (blinds or curtains) to control direct sunlight;
-Well-insulated windows.

Luminaires:

-Lighting design based on the characteristics of the furnished office, not the empty space;
-Appropriate task and ambient illuminance based on recommendations from the Illuminating Engineering Society of North America (IESNA) or Canada Occupational Health and Safety Regulations (COHSR) or other reputable sources;
-Comfortable uniformity across task surfaces;
-Appropriate luminaires: consider parabolic-louvred luminaires or luminaires with an indirect component; avoid prismatic-lensed luminaires; consider the aesthetic appearance, cost, maintenance, and energy efficiency;
-Luminaire placement and number based on illuminance and uniformity requirements, potential glare problems, aesthetic look, and acoustic conditions;
-Accent lighting that will fill shadows, create visual interest, and highlight important/interesting room and architectural elements;
-Appropriate task lighting that will provide appropriate and adjustable illuminance on specific task surfaces;
-Electronic ballasts instead of magnetic ballasts;
-Energy efficient lamps;
-Lamps with a good Colour Rendering Index (CRI) 70 or higher;
-Luminaires, luminaire shades, and source/task/eye geometry that avoid glare;
-Personal lighting controls.

Mechanical Ventilation:

-Office density within the air supply and thermal capacity of ventilation system;
-Recommended outdoor air supply rate: 8.5 L/s.p (17 cfm); preferably 10 L/s.p (20 cfm);
-Perimeter heating and cooling to offset thermal discomfort near windows;
-Air supply diffusers positioned to avoid draughts;
-Regular cleaning and maintenance of ventilation system and all components;
-Open, unrestricted supply diffusers and return grilles.

Personal Controls:

-Personal controls that allow occupants to determine their own office conditions;
-Accessible, useful, user-friendly;
-Lighting controls such as window blinds and shades, desktop or under-shelf task lighting;
-Accessible thermostats;
-Personal ventilation controls that allow the occupant to adjust supply air velocity, and direction in the workstation;
-Adjustable furnishings.

Sound Masking Systems:

-Neutral background noise provided by a sound masking system;
-Spectrum designed specifically for the office; avoid rumble or hissing noise;
-Within 45-48 dB(A);
-Constant sound masking noise in all areas so that there is no contrast with quiet areas.

Office Policy Suggestions:

-Policies that encourage etiquette and consideration for co-workers;
-Acoustic policy that asks occupants to speak quietly on the phone, use headphones, and have meetings/conversations in separate rooms;
-Complaint record to note all occupant comments and resultant feedback;
-Awareness of regular maintenance/cleaning schedules;
-Dress code that allows occupants to satisfy their thermal comfort preferences;
-Policies that allow personalization;
-Occupant consultation and participation during design.

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