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Indoor Air Quality and Thermal Comfort in Open-Plan Offices

By K. Charles, J.T. Reardon and R.J. Magee

Providing good indoor air quality (IAQ) and thermal comfort is important for employee satisfaction, well-being and performance. This Update provides guidance on key issues for achieving adequate indoor air quality and thermal comfort in open-plan offices, based on current standards and research conducted by NRC's Institute for Research in Construction and others.

Air quality and thermal conditions in open-plan offices are issues that must be addressed by the building designer, manager and owner in the design and operation of ventilation systems and office spaces. Poor air quality and thermal conditions can lead to employee dissatisfaction and discomfort, a reduction in work performance, and a greater incidence of absenteeism. Poor conditions can also affect occupants' health, creating physical symptoms such as headaches, nose, throat, eye and skin irritation, nausea and drowsiness.

Many of the causes of poor IAQ and thermal conditions are similar for all types of offices, and standards used in North America, such as those from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), can help to avoid problems. However, open-plan offices tend to be more densely populated than individual enclosed offices, a situation which can influence the amount of heat and contaminants produced in the space. It is important, therefore, that these factors be taken into account when applying standards and recommendations to the design of open-plan offices.

The purpose of this Update is to provide guidance on achieving good IAQ and thermal conditions in open-plan offices that are in mechanically ventilated and well-sealed office buildings. The Update includes recommendations that can be used to increase occupant satisfaction and comfort, and reduce physical symptoms. The prevention of more serious health conditions (e.g., asthma, cancer, hyper-sensitivity) is not addressed. If there is reason to believe that serious health concerns are related to the air quality or thermal conditions in the office, an investigation by medical and indoor environment specialists should be carried out.

This Update expands on Update No. 60, which summarized the findings of the Cost-effective Open-Plan Environments (COPE) project. IRC's partners in COPE were: Public Works and Government Services Canada, the Building Technology Transfer Forum, USG Corporation, Ontario Realty Corporation, British Columbia Buildings Corporation, Steelcase Incorporated, and Natural Resources Canada. For more information on COPE, see http://irc.nrc-cnrc.gc.ca/ie/cope/index_e.html. Three related Updates address workstation design, lighting and acoustics.

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Thermal Comfort

If temperature and humidity levels in the office are too high or too low, occupants can be dissatisfied with the environment, uncomfortable and less effective in their tasks. Comfortable conditions in mechanically ventilated buildings depend on six variables: air temperature, air velocity, relative humidity, radiant temperature, occupant's clothing insulation and occupant's activity level. ASHRAE's *Standard-55* defines a comfort "zone" based on these variables, where the majority of occupants are likely to feel comfortable.[1]

The higher density of occupants and equipment in most open-plan offices increases the amount of heat released (and thereby the cooling requirements) in the space. Thus the heating/cooling system must have the capacity to handle the occupant density, and be operated appropriately to meet thermal requirements.

According to the comfort zone diagrams,[1] comfortable temperatures are almost impossible to achieve when the relative humidity is high. High humidity also supports mould and bacterial growth, so ASHRAE recommends that relative humidity be maintained below 60%. There is no recommended lower level of humidity for achieving thermal comfort, but as dry conditions can lead to increased static electricity and health problems, such as skin irritation, the relative humidity should be greater than 30%. ASHRAE's acceptable ranges of operative temperature (a combination of air and radiant temperatures) for relative humidity levels of 30% and 60% are shown in Table 1.

Occupants vary their clothing with the seasons, so recommendations for summer and winter are given, to reflect the amount of "clothing insulation" (clo) that clothes provide. These ranges are valid for typical office activities and for air velocities less than 0.2 m/s (40 ft./min.). For acceptable operative temperatures for different levels of air velocity, relative humidity, clothing insulation and activity level, refer to ASHRAE's comfort zone diagrams.[1] Findings from an IRC field study supported what are considered by ASHRAE to be acceptable temperature ranges.[2]

Occupants in open-plan offices typically have to share one thermostat setting, reducing the control they can exert over the thermal environment. A flexible dress policy gives occupants one means to fine-tune their thermal comfort, but should not be provided as an alternative to appropriate building temperature control.

While occupants can be thermally comfortable overall, they may still experience discomfort on a specific part of their body, most commonly from drafts. Their experience of draft depends on air temperature, air velocity, and turbulence intensity (the amount of fluctuation in the air flow).[1] ASHRAE recommends that conditions be configured so that less than 20% of occupants are dissatisfied due to draft. In general, air temperature within the comfort zone and air velocities below 0.2 m/s meet this recommendation, although IRC found that a velocity of 0.1 m/s or less could lead to a further increase in satisfaction.[2]

Table 1. Examples of acceptable operative temperature ranges based on comfort zone diagrams in ASHRAE Standard-55-2004

Conditions	Acceptable operative temperatures	
	°C	°F
Summer *(clothing insulation = 0.5 clo)*		
Relative humidity 30%	24.5–28	76–82
Relative humidity 60%	23–25.5	74–78
Winter *(clothing insulation = 1.0 clo)*		
Relative humidity 30%	20.5–25.5	69–78
Relative humidity 60%	20–24	68–75

ASHRAE allows for higher air velocities in warm, humid conditions, as some research suggests that occupants welcome the cooling effect these higher velocities provide.[3] The proviso is that occupants have control over the local air speed.[1]

IRC researchers found the alignment of supply air diffusers relative to workstations sometimes led to an increased risk of draft.[2] This is most likely to be a problem with smaller workstations, where there is less opportunity for occupants to move out of the path of supply air, and where the total airflow is also likely to be higher (to cope with the greater occupant density and higher cooling load). As well, there is a greater likelihood of draft when the diffusers are angled to supply large amounts of air directly toward the occupant. When the office is reconfigured, it is important to change diffuser placement and ventilation volume to help minimize these problems.

Occupants seated next to a window tend to be less satisfied with thermal conditions.[2] Although workstations located next to windows benefit from natural lighting and a view, their occupants often experience a wider range of temperatures because of the warm or cool radiant temperatures from the window. Blinds, perimeter heating and cooling, and well-insulated windows can help minimize these problems.

Indoor Air Quality

To achieve good IAQ, many factors must be considered. These include the type and amount of contaminants in the space, the quality and quantity of the outdoor air supply, the movement of air and contaminants within the space, and the cleanliness of the office space and ventilation system.

Indoor Contaminants

Contaminants in the office space can arise from many sources. For example, outdoor contaminants from vehicles and factories, such as carbon monoxide and sulphur dioxide, can enter the building through the ventilation system, doorways or infiltration through walls. Building materials and office furnishings contain chemicals, particularly volatile organic compounds (VOCs), that are continuously being released into the indoor air. Office equipment, such as printers and photocopiers, can create ozone, and also emit VOCs. Dust and moisture can accumulate in ventilation systems and office spaces, providing a habitat for microbial contaminants.

Office occupants themselves can also be a source of contaminants, which can include the by-products of breathing and perspiring, personal hygiene products (such as perfume and deodorants), and dust and animal dander carried into work on clothing. All of the above contaminants can make the air feel dusty and stale, produce unpleasant odours, and lead to occupant dissatisfaction and discomfort.

At higher concentrations, indoor contaminants can cause physical symptoms, and in some cases lead to serious health risks. The tendency towards higher densities of occupants, furnishings and equipment in open-plan offices can contribute to increased concentrations of these contaminants.

For some contaminants, guidelines on acceptable concentrations indoors have been established. ASHRAE provides a good summary of these guidelines, including those for several contaminants whose primary source is outdoor air (carbon monoxide, nitrogen dioxide, radon and sulphur dioxide), the most commonly known VOC (formaldehyde), ozone, and respirable dust particles.[4]

For other contaminants, guidance on acceptable concentrations is not yet available. For example, while mould and VOCs have been associated with physical symptoms and dissatisfaction, there are insufficient research results to allow reliable guideline concentrations to be set.[2] In the absence of such guidelines, the concentrations of all indoor contaminants should be kept as low as possible (see recommendations below).

High carbon dioxide (CO_2) concentrations in offices can be an indirect indication of poor ventilation and contaminant build-up. At CO_2 levels above 1000 parts per million (ppm), occupants experience decreased satisfaction, perceptions of poor air quality, and increased physical symptoms.[2] Some research indicates that reducing the level to at least 800 ppm can further improve occupant satisfaction and reduce symptoms.[5] IRC research found that satisfaction improved as CO_2 concentrations decreased (for the range 1100 to 470 ppm), and that more people were satisfied than were dissatisfied

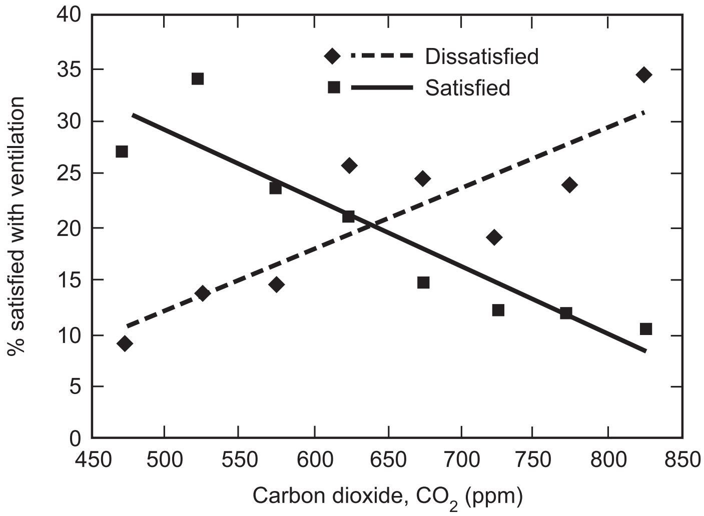

Figure 1. Percentage of occupants that were satisfied or dissatisfied with ventilation at each level of carbon dioxide concentration

when CO_2 concentrations were less than 650 ppm (see Figure 1).[2] This suggests that there may be some benefits to exceeding ASHRAE's ventilation recommendations.

Outdoor Air Supply Rate

Office spaces need to be ventilated with sufficient outdoor air to dilute contaminants and provide occupants with oxygen for breathing. For many years, ASHRAE's *Standard-62.1* recommended a minimum outdoor air supply rate of 10 litres per second per person (L/s.p), but recently this rate was reduced to 8.5 L/s.p.[4] This reduction can lead to energy savings, but the effect on occupants is unclear because research to compare these two rates has yet to be conducted. However, research suggests that outdoor air supply rates below 10 L/s.p may lead to occupant discomfort and dissatisfaction, increased physical symptoms, absenteeism, and reduced task performance.[2,5] ASHRAE's recommendation of 8.5 L/s.p should be treated as an absolute minimum outdoor air supply rate; a rate of 10 L/s.p is preferable for IAQ purposes.

Achieving adequate ventilation in the occupied space also depends on appropriate operation of the ventilation system. Special steps should be taken where possible, such as increasing the ventilation rate or isolating the area when renovating office spaces or installing new materials and furnishings, as materials typically emit the most VOCs when new.[6]

As outdoor air supply rates are determined on a per person basis, it is important to establish an appropriate outdoor air supply based on the occupancy of the open-plan office, and to revise this appropriately following any changes in occupant density.

Air Delivery Systems

Air supply diffusers and return air grilles should be positioned and operated so that air is evenly delivered to all parts of the office space, and contaminants effectively removed or diluted. Air delivery systems used in North America include traditional (mixing), displacement and personal (local) systems.[7]

Most North American open-plan offices use a traditional system. As long as this type of system is properly designed and operated, it can produce good IAQ.[7] Researchers at IRC found that workstation size, panel height, and supply diffuser location had little effect on how well a traditional system controlled contaminant concentration in an open-plan office space (using an outdoor air supply rate of 10 L/s.p).[2] However, occupants in workstations with high panels tend to be less satisfied with ventilation.[2] This is likely to be a psychological effect rather than a function of the physical environment—that is, there is an occupant perception that high panels impede acceptable airflow. For this reason, panels higher than 1.68 m (66") should be avoided.

Displacement and personal systems can both produce superior IAQ (relative to traditional systems), as long as old, contaminated air is raised sufficiently above the heads of occupants. However, these systems can also produce conditions that lead to thermal discomfort when improperly implemented. Displacement systems deliver air at floor level, which can cause drafts if the supply air temperature is not properly controlled; they also create vertical differences in temperature, which can be uncomfortable if they are too large. Personal systems improve IAQ most when air is directed towards the occupant's face; however, this can cause discomfort from drafts.

One unique feature of personal systems is that they provide individual control to occupants, allowing them to adjust air velocity, temperature and direction. Because of the opportunities for individual control, personal systems have been associated with

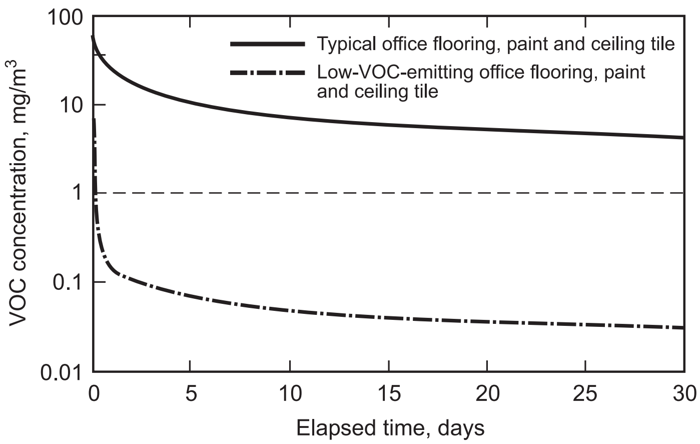

Figure 2. VOC emissions from typical office flooring, paint and ceiling tile compared with low-VOC-emission alternatives for a simulated 30,500 m^2 office space

improved satisfaction and thermal comfort, and a reduction in physical symptoms, as compared to traditional systems.[2]

Other Contributors to Good IAQ

Cleaning and Maintenance

Contaminants can accumulate in the office space and in the ventilation system itself. Regular and thorough cleaning of the space and the ventilation system equipment reduces the accumulation of dust, VOCs and microbes, and also improves occupant satisfaction and reduces physical symptoms.[2] However, because some cleaning processes temporarily distribute dust into the air, and many cleaning products contain VOCs themselves, these activities should be undertaken when the offices are not occupied.

Contaminant Source Control

The best way to improve IAQ is to prevent contaminants from entering the office space in the first place. For example, careful selection of materials and products can reduce the quantity of VOCs emitted, particularly when new materials are introduced into the office space. Figure 2 provides one example of how VOC concentrations can be reduced when low-VOC-emitting products rather than typical products are chosen.[8]

High-efficiency air filters should be used in the ventilation system, to prevent outdoor contaminants from entering the office space.

Communication

Indoor air quality can be a sensitive issue for occupants, managers and building operators. One way to avoid conflicts is to develop a clear and responsive complaints procedure. This way, concerns can be promptly addressed, clear feedback given, and IAQ problems solved quickly.

Summary of Recommendations

Setting high standards for indoor air quality and thermal comfort is important for employee satisfaction, well-being and performance. To help create a suitable environment for the occupants of open-plan offices, the following guidelines should be followed:

Mechanical Ventilation System

- Use an outdoor air supply rate that meets or exceeds ASHRAE *Standard-62.1*
- Deliver thermal conditions that meet ASHRAE *Standard-55*
- Ensure that the system has the capacity and distribution ductwork to handle occupant density, and that it is reconfigured and rebalanced when the density changes
- Regularly clean and maintain all system components
- Adjust air supply diffusers to avoid drafts
- Provide individual control over one or more of the following: air speed, air direction, temperature

Office Space

- Select low-VOC-emitting materials, equipment and furnishings
- Regularly clean floors, furniture, equipment and surfaces
- Provide shading devices and local sources of additional heating and cooling to occupants in perimeter workstations
- Avoid panels higher than 1.68 m (66")
- Choose windows with high insulation values and solar reflective qualities

Office Policy (not a substitute for adequate ventilation system operation)

- Adopt a flexible dress policy
- Develop and implement a clear and responsive complaints procedure

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