Improving indoor air quality

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The widespread concern for the health, well being, and productivity of building occupants have been an essential element in maintaining good Indoor Air Quality (IAQ). Achieving good indoor air quality in buildings continues to be a top priority for designers, building managers and occupants alike. The challenge is greater today because there are many new materials, furnishings, products and processes used in these buildings that are sources of air contaminants. The attributes of good indoor air quality include control of indoor air pollution, the introduction and distribution of adequate ventilation air, and the maintenance of acceptable temperature and relative humidity. This research is an attempt to review the main aspects of controlling IAQ (i.e. Indoor Air Contaminants, Ventilation, Temperature & Relative Humidity). The paper consists of five main parts. The first part defines the term "indoor air quality" and its relationship to worker productivity. The second part is a demonstration of the major indoor air contaminants, factors that contributes to indoor pollution levels, building materials responsible for emitting Volatile Organic Compounds (VOCs), in addition to the sorptive sink effects that describes the adsorption/desorption of VOCs from/to indoor air to/from surface materials. This part deals also with the plant life and its role in the elimination of contaminants. The third part reviews ventilation strategies highlighting the main factors affecting the performance of a ventilation system. This part also deals with those systems of ventilation that achieve energy consumption such as CO2 Demand-Controlled Ventilation (DCV), comfort ventilation, and nocturnal ventilative cooling**.** The fourth part focuses on the maintenance of acceptable temperature and relative humidity emphasizing that a practical guide to indoor air quality cannot overlook levels of temperature and relative humidity. Finally, in the fifth part conclusions are formulated focusing on the most efficient solution to indoor air quality problems.

أن تحسين خصائص الهواء في الفراغات الداخلية من اهم الأولويات التي يجب أن تحظى بالإهتمام من قبل المصممين نظرا لتاثيرها على صحة الإنسان وإنتاجيته. والتحدي في هذا المجال كبير نظرا لكثرة المنتجات والمواد الإنشائية الحديثة التي تعمل على زيادة نسبة الملوثات في الهواء. والعوامل الرئيسية التي تؤثر على خصائص الهواء في الفراغات الداخلية هي نسبة الملوثات والتهوية ودرجة الحرارة والرطوبة النسبية. هذا البحث هو إستعراض لافضل الوسائل والتقنيات التي تعمل على تحسين خصائص الهواء الداخلي. تتكون الورقة البحثية من خمسة أجزاء، الجزء الأول هو تعريف بمعنى خصائص الهواء الداخلي والجزء الثاني يستعرض الملوثات الرئيسية للهواء في الفراغات الداخلية والعوامل التي تؤثر على نسبتها وكذلك مواد الإنشاء المسئولة عن تكوين المركبات المسرطنة في الهواء. كما يتناول هذا الجزء دور النباتات في تقليل نسبة تلك الملوثات. الجزء الثالث يتناول الإستراتيجيات المختلفة لتهوية الفراغات الداخلية والعوامل المؤثرة عليها وكذلك الوسائل التي تحقق التهوية الجيدة مع الكفاءة في إستهلاك الطاقة. أما الجزء الرابع فيركز على عاملى الحرارة والرطوبة النسبية. وأخيرا الجزء الخامس من البحث يستنتج أفضل الوسائل وأكفئها لتحسين خصائص الهواء في الفراغات الداخلية.

Keywords: Indoor air quality, Contaminants, Ventilation, Building materials, Volatile organic compounds

1. Introduction

Acceptable indoor air quality was defined by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) as: "Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk." [1]

Indoor air quality (IAQ) is of great importance to health. According to the U.S. Environmental Protection Agency (EPA), many people spend >90% of their time indoors breathing air that has significantly declined in quality. The American Lung Association reports that up to 50% of illnesses over the past decade are either caused or aggravated by indoors airborne contaminant [2]. As the demand for energy efficiency has increased, buildings have been designed to be 'tighter' with less ventilation or turnover of outside air.

Indoor Air Quality (IAQ) and its relationship to worker productivity is an important subject that has received much attention in technical journals and engineering conferences. The more immediate concern in the minds of engineering design professionals is the increased cost of building operations and construction, which are the result of the higher ventilation levels associated with improved IAQ. More ventilation air requires larger equipment and heat recovery, which results in higher construction costs and operating costs. However, preventing a problem from occurring costs less than trying to repair the damage once it has occurred. It has been proved that loss of workers productivity over the life of a building, far exceed the cost of combining indoor air quality principles in the planning and design phase.

Controlling IAQ is an important aspect of a healthy indoor environment. That involves the indoor air to be freed from significant levels of odors, dust and contaminants. In addition, temperature and humidity are appropriate to the season and to activity of the building occupants. However, contemporary requirements for energy conservation, quick changes in building technologies, and the rapid increase proportion of sensitive and elderly occupants have set difficult IAQ standards for building designers, whom are responsible for creating comfortable indoor environments and clean indoor air.

Therefore, the main three aspects of controlling IAQ include:

- Elimination of indoor air contaminants,
- Proper ventilation, and
- Appropriate measures for Temperature & relative humidity.

2. Indoor air contaminants

Numerous international studies reveal that indoor air pollution poses high health risks. Some of the indoor air pollutants are likely to be important in most Egyptian major cities especially Cairo, which includes:

- Environmental Tobacco Smoke (ETS) or "second-hand smoke".
- Pollutants from stoves (CO, NOx, particulates); buildings equipped with gas- or kerosene-fueled appliances often have indoor concentrations of nitrogen oxides and carbon monoxide exceeding outdoors ambient standards. In particular, burning kerosene indoors put inhabitants at high-risk [3].
- Biological contaminants, such as mold, fungi, mites, and allergens; and household toxics, particularly pesticide sprays. Molds and other biological agents can multiply in the increasing proportion of Cairo's buildings that are closed and climate-controlled. Use of toxic pesticides in buildings in Cairo is widespread to control insects, mosquitoes, fleas, cockroaches, and etc [4].
- Toxic consumer products and building materials (e.g., solvents, paints, pesticides, asbestos, urea-formaldehyde insulation).
- Radon, which is a cancer-causing, radioactive odorless gas that is found in soils. It can become concentrated at dangerous levels in any building. Radon seeps into homes through cracks and other holes in the floor. Radon-resistant construction can control radon in buildings by reducing moisture levels and all the associated problems with increased moisture in buildings [5].

Indoor air pollutant levels are increased under some circumstances; factors that increase indoor pollutant levels can be summarized as:

- Inadequate ventilation by not bringing in enough outdoor air to dilute emissions from indoor sources and by not discharging indoor air pollutants out of the building. If too little outdoor air enters a building, pollutants can accumulate to levels that can pose health and comfort hazards. Unless they are equipped with special mechanical means of ventilation, buildings that are designed and constructed to minimize the amount of outdoor air that can "leak" into and out of the home may have higher pollutant levels than other buildings. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a building, pollutants can build up even in buildings that are normally considered "leaky."[6]

- High temperature and humidity levels.
- How old the source is and whether it is properly maintained. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted.
- How long the source emits pollutants? Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the building, release pollutants intermittently [6].

2.1. Building materials & volatile organic compounds

Volatile Organic Compounds (VOCs) are carbon-based chemical solvents distilled from petroleum or petroleum byproducts [7]. VOCs are released in a gaseous form at room temperature and are found in most materials and products used in the construction, finishing, and maintenance of interior spaces. These sources include paints, adhesives, sealants, caulks, upholstery, carpeting, composite wood products, vinyl floors, furniture finishing products, pesticides, and cleaning supplies (table 1). There are an estimated 300 different VOCs typically detected in the indoor air of non-residential buildings. Since most people spend a majority of their time indoors, it is no wonder that exposure to these toxins can cause short-term and long-term health effects, resulting in increased concern about Sick Building Syndrome (SBS) [8].

SBS is a condition in which building occupants experience symptoms that do not fit the pattern of any particular illness. Research has shown that VOCs play a large role in many SBS complaints, particularly in new or newly renovated buildings. Often this problem is compounded by even higher concentrations of VOC emissions due to the construction of modern, tightly sealed buildings (in order to reduce energy costs), and newer ventilation systems, which recycle a large amount of inside air.

Short-term symptoms of SBS include eye, nose, and throat irritation; dry mucous membranes and skin; mental fatigue and headaches; respiratory infections and cough; sensitivity to odors; and nausea. Most occupants feel relief after leaving the “sick” building. Long-term exposure to high levels of some indoor pollutants may damage the liver, kidneys, and central nervous system [8].

Deteriorated building materials and diverse furnishings have been acknowledged as a major emission source of VOCs indoors. Asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products are examples of such materials [6]. Examples of construction materials that contain VOCs are plywood made with isocyanurates, vinyl flooring made with Polyvinyl Chloride {PVC}, many paints, glues and adhesives, and almost all maintenance and cleaning products that are petrochemical- or solvent-based. These materials {and others) contribute to the 'sick building syndrome’ [7].

In addition, Interior architectural coatings such as wood-stains, varnishes, and paints are widely used in buildings. Most of these “wet” coatings contain petroleum-based solvents and thus emit a wide variety of VOCs. These VOCs can increase indoor air pollution fig. 1 [9]. Hence, understanding the emission characteristics of “wet” materials is important for preventing indoor air pollution problems. Previous studies have indicated that the emission process of “wet” materials appears to have three phases [10]:

- The first phase represents the period shortly after the material is applied but is still relatively wet. The VOC emissions in this phase are characterized by high emission rates but fast decay. It appears that emissions are related to evaporation at the surface of the material.
- The second phase, the material dries as emissions transition from an evaporation-dominant phase to an internal-diffusion controlled phase.
- The third phase the material becomes relatively dry. In this phase the VOC off-

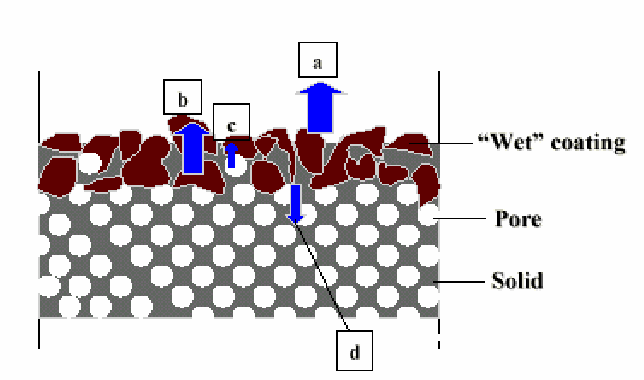

Fig. 1. Schematic representation of the emission mechanisms of a "wet" material embedded in a porous substrate. (a) = evaporation; (b) = movement of free and bound VOCs; (c) = vapor flow; (d) = diffusion to substrate (source: Yang, 2001) [9].

gassing rate decreases and so does the decay rate. The dominant emission mechanism in this phase is believed to be the internal diffusion of VOCs through the substrate [4, 5, 6]. Previous studies have also found that the emissions of "wet" materials are likely to depend on environmental conditions (e.g., temperature, air velocity, turbulence, humidity, VOC concentration in air) and also physical properties of the material and the substrate (e.g., diffusivity) [9].

2.2. Sorptive sink effects

Evidence from a variety of investigations and systematic studies suggests that building materials can also affect the transport and removal of indoor VOCs by sorption and desorption.

The term sorptive sink effects describe the adsorption/desorption of VOCs from/to indoor air to/from surface materials, which may have significant impacts on indoor air quality level [11]. The chemical composition of a material can change over time. It is more likely that old materials have a smaller amount and a fewer number of chemicals than new ones. Therefore, it may be easier for a chemical to diffuse into old materials, which can lead to greater sorption. A material can also physically change over time. For instance, the coating over a material can become worn out, which may lead to an increased surface area [11]. Researchers have found that re-emission of sorbed VOCs can elevate VOC concentrations in the indoor environment. Materials capable of depositing, adsorbing, and accumulating pollutants can influence indoor air quality during the entire service life of a building. Therefore, an accurate characterization of sorption of building materials and the sorption impact on indoor air quality is important [12].

2.3. Plant life and elimination of contaminants

The transpiration of the plants (and hence, evaporative cooling), as well as their production of oxygen play important roles enhancing indoor air quality fig. 2. certain plants are especially well suited to the elimination of contaminants. For instance, during a single day in an office, an ivy plant is able to eliminate 90 percent of the benzol contained in and released through tobacco smoke, artificial fibers, dyes and plastics. Aloe, bananas, spider plants and philodendron are effective agents against formaldehyde, which may seep from insulating foam and particle board. Trichloroethylene from lacquers and glues is best eliminated with the help of chrysanthemums and gerbera. It is certain that roots and the microbes symbiotic with root systems, and not the plants themselves, are largely responsible for eliminating contaminants [13].

With regard to humidification, plants are better agents than electrically powered air humidifiers or even humidifiers combined with air-conditioning systems, because they do not provide a favourable breeding ground for bacteria. Internal design using houseplants can help provide an environment that mimics the way that nature cleans the earth's atmosphere. When their stomata open to absorb and release air and water, the internal air is stimulated [7]. This allows the plants to capture toxins, which go to the root systems where microbes break them down. Plants also emit phytochemicals that suppress spores and bacteria. Another effective indoor plant is the gerbera daisy, which is held to be best at the removal of formaldehyde (found, for example, in facial tissues, carpets, gas stoves and plywood). The lady palm is best for removal of ammonia, and the peace lily is found to digest

Table 1
Commonly encountered VOCs and their sources (source: Nathanson, 1995) [8]

Chemical	Source
Acetone	Paint, coatings, finishers, paint remover, thinner, caulking
Aliphatic hydrocarbons (octane, decane, undecane hexane, isodecane, mixtures, etc.)	Paint, adhesive, gasoline, combustion sources, liquid process photocopier, carpet, linoleum,caulking compound
Aromatic hydrocarbons (toluene, xylenes, ethylbenzene, benzene)	Combustion sources, paint, adhesive, gasoline, linoleum, wall coating
Chlorinated solvents (dichloromethane or methylene chloride, trichloroethane)	Upholstery and carpet cleaner or protector, paint, paint remover, lacquers, solvents, correction fluid, dry-cleaned clothes
n-Butyl acetate	Acoustic ceiling tile, linoleum, caulking Compound
Dichlorobenzene	Carpet, moth crystals, air fresheners
4-Phenylcyclohexene (4-PC)	Carpet, paint
Terpenes (limonene, a-pinene)	Deodorizers, cleaning agents, polishes, fabrics, fabric softener, cigarettes

Fig. 2. Plants are an important elements, not only for their appearance, but because they raise oxygen levels in the building and eliminate contaminants (source: Jones, 1998) [14].

human bioeffluents. The areca palm is considered the more effective for indoor absorption. There are four criteria to rate the plants: removal of chemical vapours, ease of growth and maintenance, pest resistance and transpiration rate [13].

It worth mentioning that plant needs an environment providing more than the minimum level for survival (i.e. the compensation point between photosynthesis and respiration). This can only be achieved by choosing the best plants and location and combining plants that have long life expectancies. Light being the source for photosynthesis plants should especially be used in very bright, naturally lit areas such as winter gardens, atria and open glassed-in office areas. When lighting conditions are poor, the photosynthesis and pollutant breakdown of plants are equal. If forced to grow in an environment below the compensation point, they receive too little light, begin to fade after a while and eventually die [7].

3. Ventilation

Historically, the involvement with the problem of the removal of indoor contaminants through ventilation was realized into early Victorian buildings fig. 3-a. In the

Houses of Parliament of 1835-52, Sir Charles Barry's main task was the problem of heating and especially ventilation. The building had had a long and difficult history of attempting satisfactorily to ventilate the debating chambers. The uppermost environmental concern was to bring fresh air into the building without causing draughts. This was achieved by distributing fresh, warmed air through a network of ducts and flues incorporated into the walls, floors and roof structures. An important consideration on the extract side of the systems was the removal of the products of combustion from gas lightning [15].

In addition, Passive downdraft evaporative cooling is a technique that has been used for many centuries in Islamic architecture. In this tradition, wind-catchers guide outside air over water-filled porous pots, causing evaporation and bringing about a remarkable drop in temperature before the air enters the interior. Contemporary natural downdraft evaporative coolers are towers-like devices supplied with wetted pads and sprays at the top fig. 3-b [16], that provide cool air by gravity flow. In arid regions, these devices can be used for cooling residential and commercial buildings, as well as outdoors private and public areas.

In most cases, improvements in IAQ are accomplished by increasing the Outdoor Air (OA) to a building. Ventilation is the process of supplying outdoor air to an enclosed space and removing stale air from this space. It can control the indoor air quality by both diluting the indoor air with less contaminated outdoor air and removing the indoor contaminants with the exhaust air.

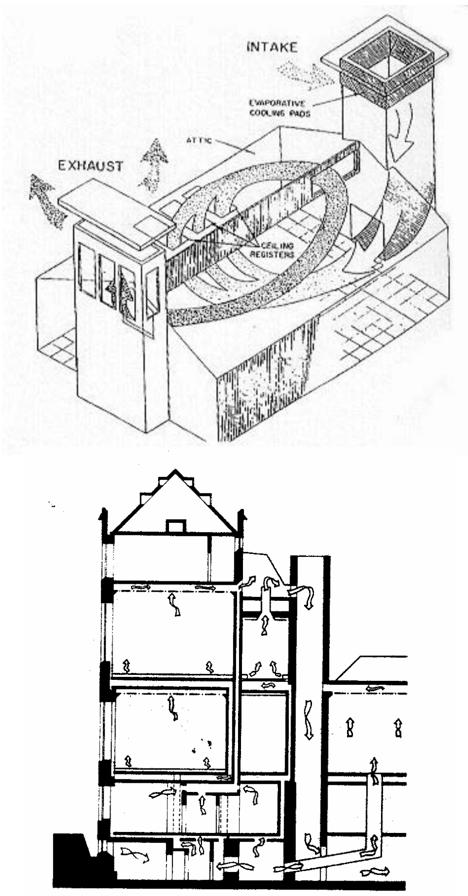

Fig. 3-a. Sir Charles Barry, Houses of Parliament, London, 1835-52. River front heating and ventilating system. Cross-section (lower left corner) (source: Hawkes, 1996) [15].

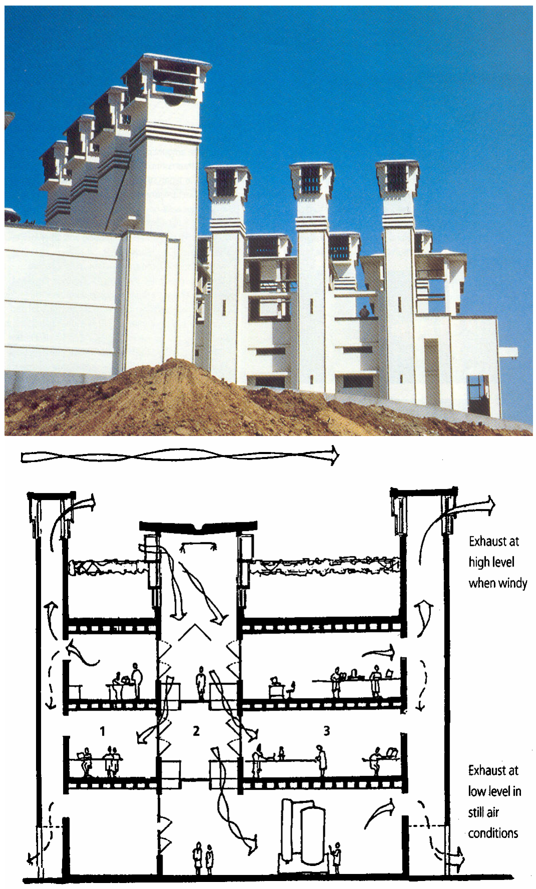

Fig. 3-b.Torrent Research Center, Ahmedabad, India (upper and lower right) (source: Hagan, 1999) [16].

Indoor air always starts as one thing- outdoor air. Unfortunately, outdoor air may itself be of poor quality, which is the case in most major cities in Egypt (table 2). Today's requirements for fresh-air exchange in buildings mean that any pollution in the outdoor air will be brought indoors. Thus people may be able to find relief in tightly sealed buildings. Usually, HVAC filtration purifies the outdoor air so that indoor air has lower quantities of the same contaminants. When indoor air tests reveal contaminants that do not exist in the outdoor control, it suggests that something is "growing" inside.

Public buildings, because of their high internal heat gains from lighting, appliances and occupants, tend to be air-conditioned. Meanwhile, there is a trend towards natural ventilation. Buildings do not have to be either air-conditioned or naturally ventilated. There is actually a continuity of solutions from which the best compromises of good IAQ [18].

Ventilation costs are of great concern because the outdoor air needs to be heated in winter, cooled in summer, and filtered. However, inadequate ventilation must be avoided because of the costs incurred due to decreased occupant productivity and occupant health care. Therefore, it is necessary to supply minimum OA ventilation rates to the indoor environment that are consistent with acceptable IAQ while avoiding the energy penalties associated with conditioning large volumes of OA [10].

When proper source control has been applied, less ventilation is required to achieve good IAQ. Natural or mechanical ventilation is an effective way of reducing the level of pollution if designed and constructed in a way that the outdoor air supply reaches the occupants. Hence, the main factors affecting the performance of a ventilation system are:

- *Air distribution:* Ventilation air is often unevenly distributed in a building. Ideally, all occupants should benefit equally from the outdoor air being circulated to a space: that is, the air should reach all the occupied zones of the building [19]. Hence, there is a need for reliable and easy to use measurement techniques that can provide information about the ventilation and air distribution within buildings, in order to verify performance or trace possible reasons for insufficient air quality. Recent development of tracer gas methods offer powerful techniques that can cope with such cases in all types of buildings, whether mechanically or naturally ventilated [20].
- *Air leakage:* Air leakage is the infiltration of air through the building envelope. The amount of air leakage depends on the airtightness of the building envelope and the pressure difference across it caused mainly by wind and stack effect [19].
- *Contamination source/local ventilation:* When powerful contamination sources are present in a building, leading to occupant complaints, the building user may be inclined to increase the ventilation rate to speed up the dilution process. Ventilation alone does not ensure acceptable IAQ where a main source of contaminants is present. It is necessary to

Table 2
Concentrations of air pollutants in greater Cairo (ug/m^3). It is assumed that indoor concentrations are identical to outdoor concentrations or, in effect, that people in Cairo are exposed to outdoor concentrations of pollutants for 24 hours per day (source: Nasralla, 1993) [17]

Pollutant	Concentration		U.S. standard		WHO guideline	
Sulfur Dioxide	40-156	annual mean	80	annual mean	40-60	annual mean
Particulate Matter	349-857	annual mean	75	annual mean	60-90	annual mean
Nitrogen Oxides	90-750	hourly means	100	annual mean	320	hourly mean(NO2)
Carbon Monoxide	1,000-18,000	hourly means	40,000	hourly mean	10,000	8-hour mean
Lead	0.5-10	annual mean	1.5	quarterly mean	0.5-1.0	annual mean
Ozone	100-200+	hourly maximum	235	hourly maximum	150-200	hourly mean

remove the contaminants at the source by using local exhaust. In the case of a contaminant source such as a photocopier, the exhaust of the photocopier should be directly connected to the outside [19].

3.1. CO2 demand-controlled ventilation

Studies of building occupancy have shown that CO2 is exhaled at a rate dependent on occupant density and activity level. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends ventilation rates for buildings based on the maximum number of occupants. For buildings such as office buildings and schools, where the number of occupants varies with time, it may be possible to control ventilation rates based on the number of occupants at a given time [10].

As a result, in buildings where the occupants are the primary pollutant source, the Indoor Air Quality Procedure allows for the control of outdoor ventilation air based on the use of CO2 as an alternate measure of occupancy. This has recently led to the increased application of relatively accurate, CO2 sensors in a system called Demand-Controlled Ventilation (DCV).

DCV is a control approach that modulates the position of the outdoor ventilation air dampers in response to sensed levels of an indoor pollutant. In spaces where the occupants are the primary pollutant source, CO2 has been used as an alternate indicator of pollutant concentration. This control strategy has been shown to reduce energy consumption [10].

3.2. Comfort ventilation & nocturnal ventilative cooling

Natural ventilation may be used to increase comfort (air movement), for health (air change) or for building cooling (wind speed). There are two ways in which ventilation can improve IAQ:

- *Comfort ventilation:* is a direct physiological effect; by letting in more wind by opening the windows the indoor airspeed is increased, which will make the occupants feel cooler. Introducing outdoor air with a given higher wind speed into a building may provide a direct physiological cooling effect even when the indoor air temperature is elevated; this is particularly the case when the humidity is high, as the higher air speed increases the rate of sweat evaporation from the skin, thus minimising the discomfort that occupants feel when their skin is wet.
- *Nocturnal ventilative cooling:* is an indirect ventilation strategy; by ventilating the building only at night, and to use this air to cool the interior mass of the building during the following day. During the day, the cooled air mass reduces the heat build-up rate of the indoor temperature and thus provides a cooling effect [7]. In other words the thermal mass works in conjunction with the natural ventilation scheme, allowing ventilation during unoccupied periods to store coolth within the mass and helps to reduce the maximum temperatures produced during occupied periods. This represents a significant reduction in energy costs when compared to a standard air-conditioning (fig. 4)[21].

In the ventilation systems mentioned before it is advantageous to ensure that buildings users can operate the building systems and equipment. As much control as possible should be given to individual users, without compromising the effectiveness and efficient control of the overall system. This controllability of systems builds in a capacity for personal control over the immediate indoor environment, assures that the global indoor environment is within acceptable limits by bringing air supply points and controls for air quality as close to individual workstations as possible. In addition it balances control system advantages against energy use and maintainability (fig. 5). And as demonstrated before the attributes of good indoor air quality (fig. 6) includes control of indoor air pollution and the Introduction and distribution of adequate ventilation ari. In addition, maintenance of acceptable temperature and relative humidity is of gread importance.

4. Moisture (maintenance of acceptable temperature and relative humidity)

A practical guide to IAQ cannot overlook temperature and humidity, because thermal

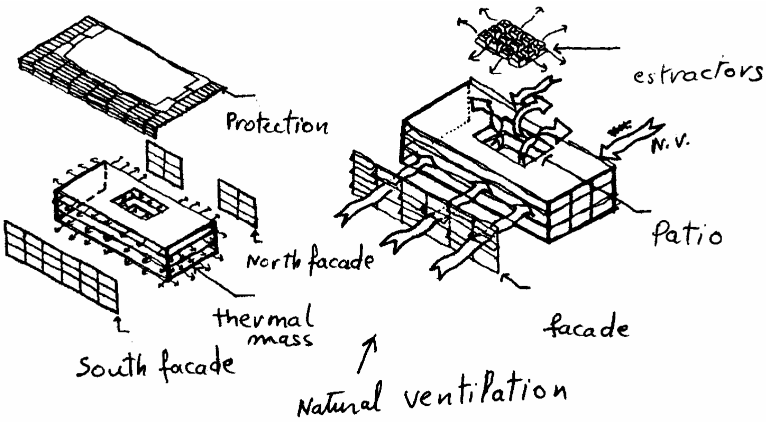

Fig. 4. The thermal mass works in conjunction with the natural ventilation (source: Francis, 1999) [21].

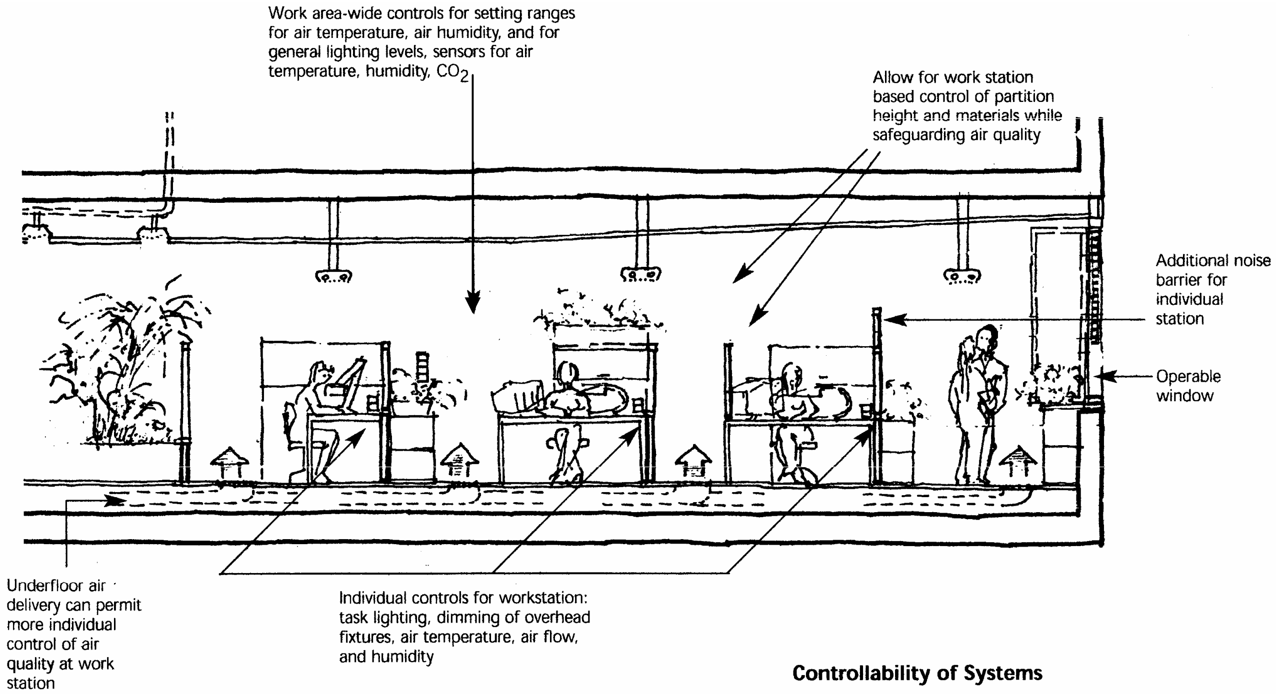

Fig. 5. Controllability of ystems (sourse: tormenta, 1999) [22].

comfort concerns contribute to many complaints about "poor air quality." Furthermore, temperature and humidity are among the many factors that affect indoor contaminant levels [18]. In addition, There is no practical way to eliminate all mold and mold spores in the indoor environment; the way to control indoor mold growth is to control moisture.

Temperature and relative humidity are two of several parameters that affect indoor air quality (table 3). Satisfaction with the thermal environment can also be influenced by such factors as radiant temperature, air velocity, occupant activity level, and clothing. ASHRAE Standard presents guidelines that are intended to achieve thermal conditions that at least 80% of the occupants would find acceptable or comfortable. Relative humidity

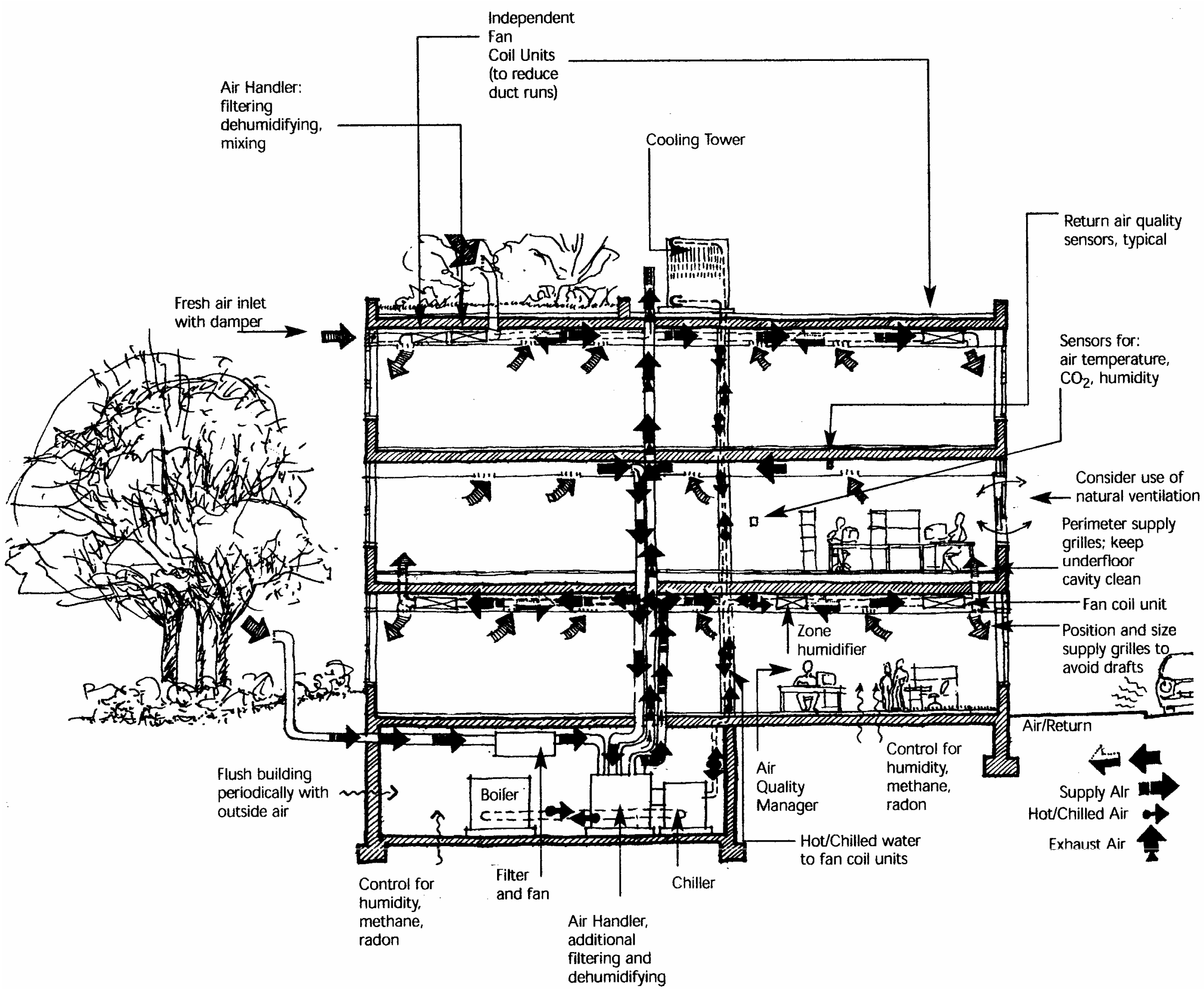

Fig. 6. Attributes of good indoor air quality (sourse: tormenta, 1999) [22].

levels below 25% are associated with increased discomfort and drying of the mucous membranes and skin, which can lead to chapping and irritation. Low relative humidity also increases static electricity, which causes discomfort and can hinder the operation of computers and paper-processing equipment. High humidity levels can result in condensation within the building structure and on interior or exterior surfaces and the subsequent development of mold and fungi [23].

Water vapor itself is not directly a pollutant in the normal sense, but high moisture content can lead to the growth of biologicals in the building envelope and on building surfaces. These biologicals can produces allergens and toxins and can also degrade building materials. The single most important requirement in this regard is that all rooms known to produce significant amounts of moisture (e.g. bathrooms) must have local ventilation to exhaust the moisture directly outdoors. Ventilation alone cannot control moisture unless the outdoor air is relatively dry. Dehumidification (e.g. from an air conditioner) is necessary to remove moisture when the outdoor air has high moisture content. In the most extreme climates (hot and humid, or cold and dry), keeping the ventilation system itself from drawing moist air into the building envelope where it might, as mentioned before, condense and cause decay is of great importance [24].

Table 3
Factors and sources affecting indoor air quality and comfort (source: Nathanson, 1995) [23]

Factor	Source
Temperature and humidity extremes	Improper placement of thermostats, poor humidity control, inability of the building to compensate for climate extremes, tenant-added office equipment and processes
Carbon dioxide	People, combustion of fossil fuels (e.g., gas and oil furnaces and heaters)
Carbon monoxide	Automobile exhaust (garages, loading docks, air intakes), combustion, tobacco smoke
Formaldehyde	Unsealed plywood or particleboard, urea formaldehyde foam insulation, fabrics, glues, carpets, furnishings, carbonless copy paper
Particulates	Smoke, air inlets, paper, duct insulation, water residue, carpets, HVAC filters, housekeeping
Volatile organic compounds (VOCs)	Copying and printing machines, computers, carpets, furnishings, cleaning materials, smoke, paints, adhesives, caulking, perfumes, hairsprays, solvents
Inadequate ventilation (insufficient outside air, insufficient airflow, inadequate circulation)	Energy-saving and maintenance measures, improper system design or operation, occupant tampering with HVAC system, poor office layout, system unbalanced
Microbial matter	Stagnant water in HVAC system, wet and damp materials, humidifiers, condensate drain pans, water towers

5. Conclusions

To ensure good IAQ, designers must consider and provide for control of possible sources of indoor contaminants, ventilation, thermal comfort, and humidity. Provision of good air quality requires a conscientious effort to estimate the impact of the soil and outdoor sources before proceeding with the design. In case of renovation and adaptive re-use, diagnose the existing structure and materials and make necessary relief.

Considerations have to be taken by designers to realize better indoor environment through controlling pollutant sources, which is the most effective strategy to minimize exposure of the occupants to contaminants in indoor air. In addition, minimizing occupant exposure to pollutant sources through material selection, isolation of areas with strong sources such as smoking, copying and cooking. Using local exhaust when necessary to control strong sources is essential. Using low-VOC-emitting construction and maintenance materials is the most effective means of minimizing occupant exposure to chemicals. Strategies to reduce the effects of VOCs include using higher ventilation rates (achieved by increasing air change per hour), use of charcoal filters or the selective use of certain houseplants. The transpiration of the plants (and hence, evaporative cooling), as well as their production of oxygen play important roles enhancing indoor air quality. In any ventilation system as much control, as possible should be given to individual users, without compromising the effectiveness and efficient control of the overall system.

Moisture can lead to the growth of biologicals in the building envelope and on building surfaces. These biologicals can produces allergens and toxins and can also degrade building materials. Therefore, It is essential to provide enough ventilation to all spaces where humidity is generated, or where moisture can accumulate. Worth emphasizing that clear IAQ responsibility assignments are essential to ensure that the building works well as a system. That means, among other things, that there is a clearly defined individual responsible for the indoor air quality of the building. Hence, those whom are responsible for the performance of the building must be properly educated and trained.

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