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Indoor/Outdoor Air Exchange – Balancing Energy, Building Comfort and Health Issues in Extreme Climates

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Abstract

The development of effective benchmarks, standards and regulatory measures for buildings designed and constructed for 100% year round air-conditioned indoor environments pose extreme challenges.

This is particularly true in the recently developed dense urban areas in the GCC region where twenty-four hour, seven-day a week conditioned indoor environments must optimize the balance between the unwanted infiltration / exfiltration of building facades, the intake of re-fresh air in an energy efficient manner and the treatment of both the unwanted and mechanically required hot, humid particulate laden outdoor air intake in order to make the indoor environment comfortable, healthy and safe.

Keywords: Building Envelope Permeability, Fresh Air Ventilation, Indoor Air Quality

Building Envelope Permeability

The effectiveness of reducing building envelope air leakage on saving energy has been well established; studies and research since the early 1990's have confirmed and reconfirmed that well-constructed weather sealed wall and roof assemblies can contribute to energy saving and thus increased sustainability in the built environment. **(i)**,**(ii)**,**(iii)**,**(iv)**

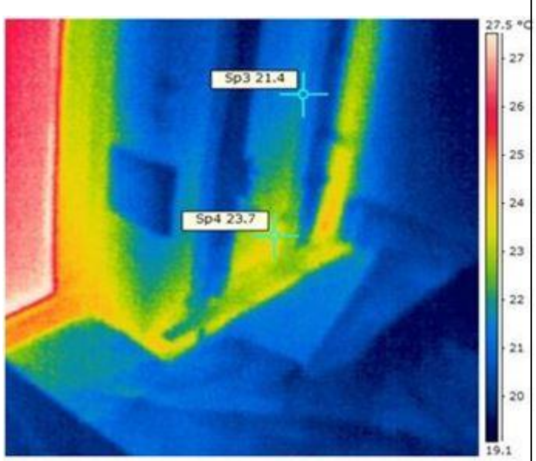

FIGURE 1A

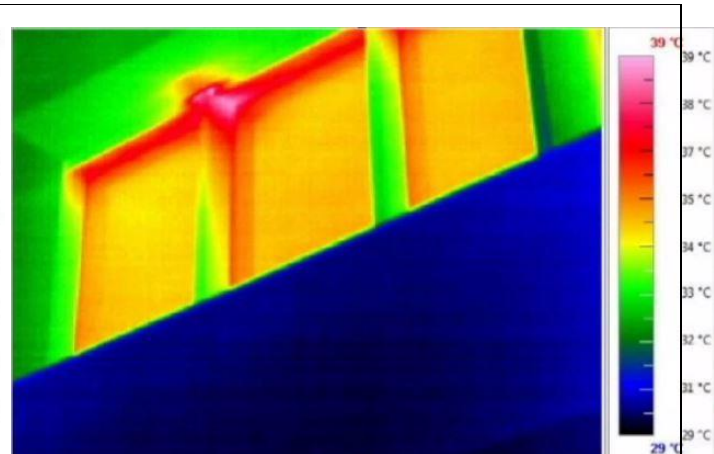

FIGURE1B

Two Infrared Thermographs indicating building envelope system failure and outside air infiltration. 1A shows air infiltration through light weight concrete block construction; 1B shows degraded window gasketing . ©GBSI

Increased Importance of Building Envelope Permeability in the GCC

The petroleum based wealth of several of the Gulf countries has allowed a ten-fold increase of the built environment since the beginning of the twenty-first century; creating contemporary global capitals where residents live, work, shop, travel and recreate in 24/7 air conditioned environments. **(v)** These 100 percent conditioned environments use massive amounts of energy; estimates routinely range from 60 to 75 percent of domestic and commercial building electrical usage is devoted to air conditioning alone. **(vi)**

As an example, the UAE average year temperatures is above 35^{o} with 350 + annual days of unbroken sunshine. To maintain a typical home in Abu Dhabi, the national capital, at an indoor temperature of 21^{o} Celsius the resulting heat energy that would need to be displaced would equal 2971 cooling degree days in 2012. **(vii)**

Like the developed western world prior to the oil crises of the early 1970's, historically cheap energy costs have allowed this never before seen rate of new construction to proceed in an environment where sophisticated building designs and ambitious timetables of development strained the locally available construction technology and expertise (with some notable exceptions **(viii)**). The result has frequently been less than efficient buildings with either design or supervision inconsistencies leading to poor building envelope performance in terms of both insulative membranes and air tight weather seals.

As mentioned un- planned, un-wanted and un-controlled air leakage through the building envelope will contribute to energy wastage and higher energy costs. However, energy wastage for warming a building a moderate climate with a heating season of four to five months is vastly different from the energy wastage for cooling a building year round in desert conditions. Beyond the number of cooling or heating degree days there is the intractability of the Second Law of Thermodynamics which states in essence that heat energy moves one way only - from hot to cold. We may control the source for heating a building by turning down a thermostat however we cannot turn down the thermostat on the un-relenting, un-mitigated, and ever constant sun.

Moreover this un-planned for outdoor / indoor air exchange caused by poor building envelope system failure allows the desert inside where it eventually accumulates in the A/C system. The outdoor air gathers dust, salt and biological spores as it travels the trade currents from distant subtropical land masses and across vast deserts and high salinity bodies of water.**(ix)**

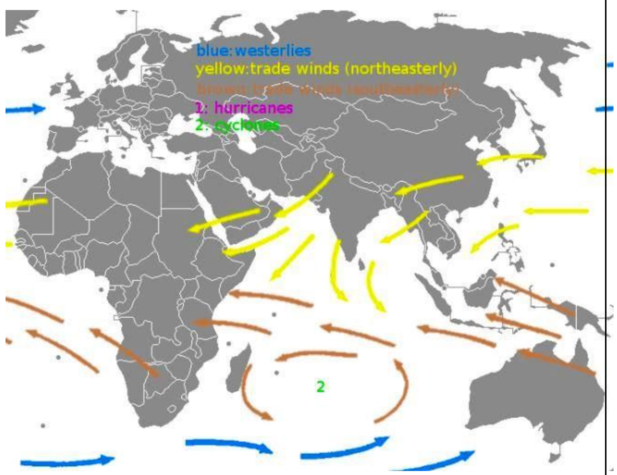

FIGURE 2A

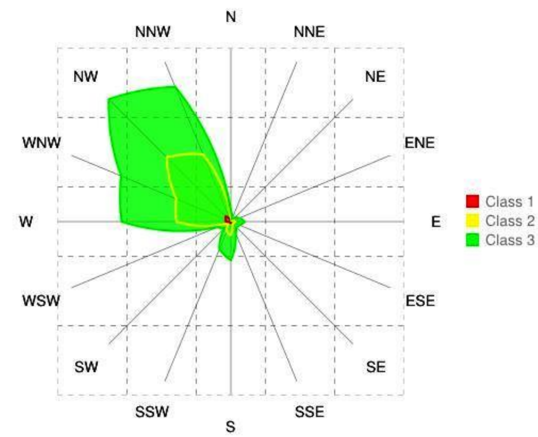

FIGURE 2 B

2A is a global map indicating major trade wind currents affecting the GCC area originating in the Indian subcontinent. 2B is a wind-rose diagram showing average annual wind direction for Dubai ,UAE (ix)

Comparison of international and GCC regional permeability rates

'Unplanned' building envelope infiltration or exfiltration and planned rates of fresh air ventilation have one thing in common – they are both forms of indoor/outdoor air exchange. Figure 4 is a listing of GCC regional and international envelope permeability standards as the various codes measurement standards have been converted into and expressed in a single formula template i.e.: $m^3/h/m^2$@50pa.

Sustainability Code Title	Permeability Standard	convert to m3/h	convert to @50 Pa	ACH @ 50Pa	ACH @ 4Pa
Abu Dhabi Municipal Code	2.0 L/s/m2 @75 Pa	7.2 m3/h/m2 @75	5.5 m3/h/m2 @50 Pa	4.3 ACH @50 Pa	0.82 ACH @4 Pa
Dubai Green Building Regulations	10 m3/h/m2 @50 Pa		10 m3/h/m2 @50 Pa	7.7 ACH @50 Pa	1.49 ACH @4 Pa
Masdar City Performance Specification	5 m3/h/m2 @50 Pa		5 m3/h/m2 @50 Pa	3.8 ACH @50 Pa	0.74 ACH @4 Pa
Estidama Pearl BUILDING Rating System (RE-R1)	3.64 L/s/m2 @75 Pa	13.04 m3/h/m2 @75	9.55 m3/h/m2 @50 Pa	7.6 ACH @50 Pa	1.42 ACH @4 Pa
Estidama Pearl BUILDING Rating System (RE-R1)	2.0 L/s/m2 @75 Pa	7.2 m3/h/m2 @75	5.5 m3/h/m2 @50 Pa	4.3 ACH @50 Pa	0.82 ACH @4 Pa
Estidama Pearl VILLA Rating System (RE-R1)	0.35 ACH @4 Pa	0.45 m3/h/m2 @4	2.3 m3/h/m2 @50 Pa	1.8 ACH @50 Pa	0.35 ACH @4 Pa
Estidama Pearl VILLA Rating System (RE-2)	0.20 ACH @4 Pa	0.26 m3/h/m2 @4	1.18 m3/h/m2 @50 Pa	0.9 ACH @50 Pa	0.20 ACH @4 Pa
Uniited Kingdom L1A Regulations	10 m3/h/m2 @50 Pa		10 m3/h/m2 @50 Pa	7.7 ACH @50 Pa	
United States Department of Energy	max 5 ACH @50 Pa		6.5 m3/h/m2 @50 Pa	5.0 ACH @50 Pa	
France	2.5 m3/h/m2 @4 Pa		13.5 m3/h/m2 @50 pa	11.0 ACH @50 Pa	
Germany (Passiv Haus)	0.6 ACH @50 Pa		0.78 m3/h/m2 @50 Pa	0.6 ACH @50 Pa	
Sweden	0.8 L/s/m2 @50 Pa	2.88 m3/h/m2 @50	2.88 m3/h/m2 @50 Pa	2.4 ACH @50 Pa	
Belgium	3.0 ACH @50 Pa		3.90 m3/h/m2 @50 Pa	3.0 ACH @50 Pa	
Norway	1.5 ACH @50 Pa		1.95 m3/h/m2 @50 Pa	1.5 ACH @50 Pa	

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FIGURE 4 Comparison of GCC regional and international building envelope maximum air permeability rates. Rates are converted to a single formula and compared to regional energy ACH guidelines . ©GBSI

The last column further converts these envelope permeability rates into Air Changes per Hour (ACH) @ 4Pa using a residential sized volume for a common comparison.

One can note that the required maximum ACH rate used in the energy calculations to meet the Estidama Pearl Rating System requirement of 0.35 (equivalent to the average rate for a two story dwelling as per Part L 2007 **(x)**) is a flow rate nearly four times that allowed by mandatory building envelope permeability of Part L 2002 at 1.49; three times of Part L 2005 at 1.06 and at 0.74 it is two times more than the indoor/outdoor exchange of the most stringent local code, the Masdar Energy Guidelines **(xi)**

Table 4.21 Empirical values for air infiltration rate due to air infiltration for rooms in buildings on normally-exposed sites in winter — dwellings; partial exposure

Air permeability / ($m^3/m^2 \cdot h$ at 50 Pa)	Infiltration rate (ACH) for given building size / h^{-1}							
	1 storey (10 m × 8 m × 2.75 m)* (Height to roof: 5.5 m)		2 storeys (10 m × 8 m × 2.75 m)* (Height to roof: 8.0 m)		Apartmts (storeys 1–5) (10 m × 8 m × 2.75 m)* (Floor spacing: 3.0 m)		Apartmts (storeys 6–10) (10 m × 8 m × 2.75 m)* (Floor spacing: 3.0 m)	
	Peak	Ave	Peak	Ave	Peak	Ave	Peak	Ave
20.0 (leaky)	1.60	1.15	1.50	1.00	1.95	1.40	2.25	1.60
10.0 (Part L (2002))	0.80	0.60	0.75	0.50	1.00	0.70	1.15	0.80
7.0 (Part L (2005))	0.55	0.40	0.55	0.35	0.70	0.50	0.80	0.55
5.0	0.40	0.30	0.40	0.25	0.50	0.35	0.70	0.40
3.0	0.25	0.20	0.25	0.15	0.30	0.25	0.35	0.25
Air change rate at 50 Pa (/ h^{-1})		11.80		8.15		11.80		11.80
ACR_{50} divisor		20.6		17.0		17.3		15.1

* (Length × width × height) for each storey; for apartments, air leakage is based on each apartment being pressure tested separately

Note: tabulated values should be adjusted for local conditions of exposure

FIGURE 5 Excerpt from CIBSE Guide A: Environmental Design, 2006 (x)

Whether using theoretically calculated rates such as the ACH used in energy modeling or rates calculated from field-testing data of artificially induced pressurization, the wide disparity between the effective real time volumes of indoor/outdoor air exchange indicated by these figures is a highly probably contributor to the so called ‘performance cap’ in operational energy performance of many sustainability code rated buildings now being observed.

Important as that distinction is however, there is an additional factor that is of even greater importance as it is also a product of living in a 100 percent air conditioned environments – indoor air quality and its effect on human health.

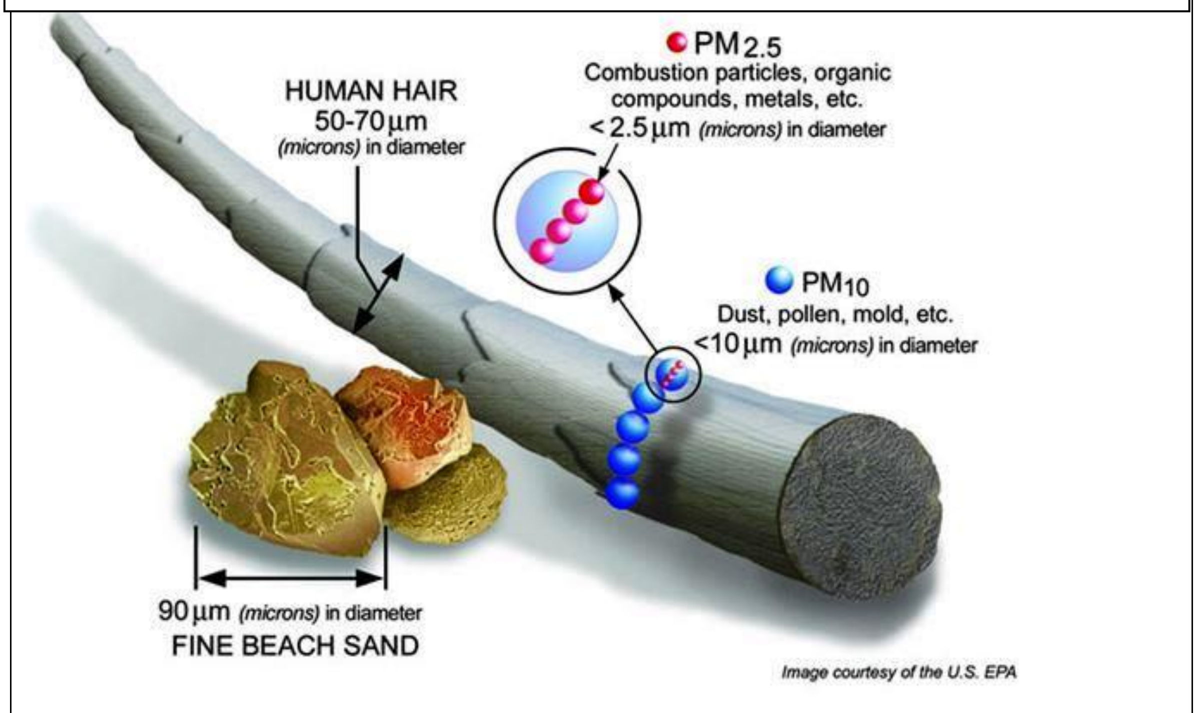
Indoor Air Quality (IAQ)

The air breathed inside homes, offices and schools can trigger and exacerbate a variety of adverse health conditions. Outdoor pollutants that have infiltrated and then accumulate within a building often produce indoor air quality (IAQ) that is more polluted than outside air. Various indoor pollutant sources release gases or particles into the air diminishing air quality. Indoor pollutant levels are further increased if there is inadequate ventilation, high room temperatures and high humidity levels. While each pollutant source may not individually pose a significant health risk, the cumulative effect of multiple indoor pollutants found within most office buildings, schools and homes increase potential health problems.

While there are numerous interior sources of air pollutants ranging from cleaning products; pesticides; air fresheners; pet allergens to leaky drains and pressed wood furnishings; it is the outdoor air that infiltrates our buildings from leaky facades or inadequately treated system re-fresh air inhaled that contains the minute particulate matter which is absorbed and then recycled in our air conditioned environments that that can pose the greatest health dangers.

Inhaled particle matters contribute to several health conditions, including but not limited to, reduced lung function, aggravated asthma, chronic bronchitis, irregular heartbeat, non-fatal heart attacks, and some cancers. **(xii)** High particle levels are likely to aggravate existing health conditions for those with heart or lung diseases. Older adults and people with diabetes are at greater risk to adverse health conditions from air pollutants, possibly due to undiagnosed heart or lung disease. Children are also at higher risk for health problems due to high particle matters because of continued lung development; high activity levels; and increased likelihood of asthma or acute respiratory diseases. **(xiii)**

FIGURE 6 –Comparison diagram of breathable air borne particulate sizes.
US Environmental Protection Agency: Particle Pollution and Your Health. (xiii)



IAQ Health Concerns in the Gulf Region

Indoor air quality in the Gulf region is of particular interest because high temperature and humidity levels require people in the region to live in twenty-four hour, seven day a week air-conditioned environments. High room temperature and humidity levels can significantly increase concentrations of mold, mildew, bacteria and dust mite pollutants. Air quality in the Gulf region is also uniquely impact by dust storms, high levels of desert particulate matter, transportation emissions and smog formation. **(xiv)** Researchers are beginning to study the health impacts of compromised indoor air quality in the Gulf region.

Sandstorms, carrying large amounts of bacteria, fungi and pollen allergens, typically hit the United Arab Emirates (UAE) eight to ten times a year.**(xv)** These sandstorms are partially attributed to the 25% increase in respiratory disorder related hospital admissions in the UAE over the last few years. **(xvi)** As of June 2013, the Environment Agency-Abu Dhabi **(xvii)** reported that the amount of dust in the air in the UAE was higher than considered safe for those suffering respiratory conditions on one-third of the days for the year to date. **(xviii)** The high levels of outdoor pollutants increase the risk for greater concentrations of indoor air pollutants.

As people in the Gulf region spend more time indoors due to climatic conditions, air pollutants found indoors in the UAE demonstrate the regional increased risk of adverse health conditions in homes, offices and schools due to air pollutants. Research of over 1,500 Emirati household members in rural and urban areas of all seven emirates of the UAE found that significant percentages of homes in the UAE had quantifiable household concentration of sulfur dioxide (30%), formaldehyde (29%), hydrogen sulfide (12%) and nitrogen dioxide (9%). **(xix)** Researchers found that household members living in homes with measurable levels of sulfur dioxide, nitrogen dioxide and hydrogen sulfide were twice as likely to have doctor-diagnosed asthma than households without significant pollutant levels. **(xx)** Shortness of breath, difficulty breathing, chest tightness, and cough were also associated with these household members. **(xxi)**Due to the increase levels of formaldehyde in household where incense is burned daily, household members in these homes were more likely to report headaches, dizziness, forgetfulness and difficulty concentrating. **(xxii)** Tobacco smoking in the homes was associated with increased wheezing, doctor-diagnosed asthma, dry cough at night, shortness of breath and difficulty breathing/chest tightness. **(xxiii)**

Children are one of the most vulnerable populations susceptible to health issues due to poor IAQ. Therefore, air pollutants within schools and education facilities should be minimized as many children spend over 30 hours a week within these buildings. Tests in eight schools in the UAE, including five state and three private schools, found excessive levels of carbon dioxide in one classroom and levels above the comfort range for volatile organic compounds in all eight classrooms. The carbon dioxide level in all eight classrooms was very high, which can lead to fatigue and sleepiness. **(xxiv)** A 2012 study analyzing air quality in four state schools in the UAE found dangerously high levels of total particulate matter in the classroom air. While international guidelines recommend a maximum of 15 milligrams per meter cubed, the study found between 200 and 250 milligrams per meter cubed. The study also found the level of volatile organic compounds including paints, building materials and cleaning products, which should be a maximum of 250 milligrams per meter cubed, at more than 1 000 milligrams per meter cubed in some schools. Carbon-dioxide levels were above maximum levels at 1500 parts per million and above. The schools met the guideline levels for ozone and carbon monoxide levels.**(xxv)**

Ventilation (Fresh Air)

Ventilation is a process by which fresh air is provided to replenish lost interior air or to dilute concentrations of potentially harmful pollutants in a space and remove these substances from the space. The main reasons for ventilating occupied or unoccupied spaces within a building are as follows:

- Restore the oxygen supply.
- Reduce the carbon dioxide, odors and process emissions
- Prevention of explosive vapor mixtures in unoccupied plant spaces.
- The re-supply of 'fresh air' is perceived as a positive contribution to the ambient comfort for building occupants.

There are three methods or modes of ways indoor space ventilation:
Natural Ventilation: when the air movement due to winds or temperature differentials occurs or passes through when it is needed or desired by manual control such as opening a window; *Mechanical Ventilation:* when the air movement is driven by a purposely designed mechanical fan system, which normally consists of a fan, either blowing the air into a room or exhausting the air out of it operating at programmed times using ductwork, diffusers or simply openings guide air to where the ventilation is needed or; *Mixed Mode* which is a combination of natural and mechanical ventilation.

Mechanical ventilation is desirable if not required for human health and comfort in areas where the ambient outside air is of naturally of low quality or with a high particulate count. These conditions occur in many regions of the world and some governmental regulators have issued guidelines to alert inhabitants of these areas to the dangers. As an example specific areas in the US southwest (which has the same hot- dry temperate zone as the UAE **(xxvi)**)
Consistently exhibit particulate counts above recommended health guidelines. **(xxvii)**

A common type of an air handling unit in the United Arab Emirates is shown in the **Figure 7**. The fresh air that is taken from the outside is passed through a pre-filter and then an additional of filter or filters, where the contaminants are removed. After that the air is passed through a cooling coil that typically cools the air to approximately 12-14^{o}C , and finally this cooled air is released into the room using a supply fan. Total Heat recovery from the exhaust is usually used to reduce the energy consumption and sometimes double heat recovery is used to additionally raise the fresh air temperature after the coil to a neutral air temperature of 21^{o}C.

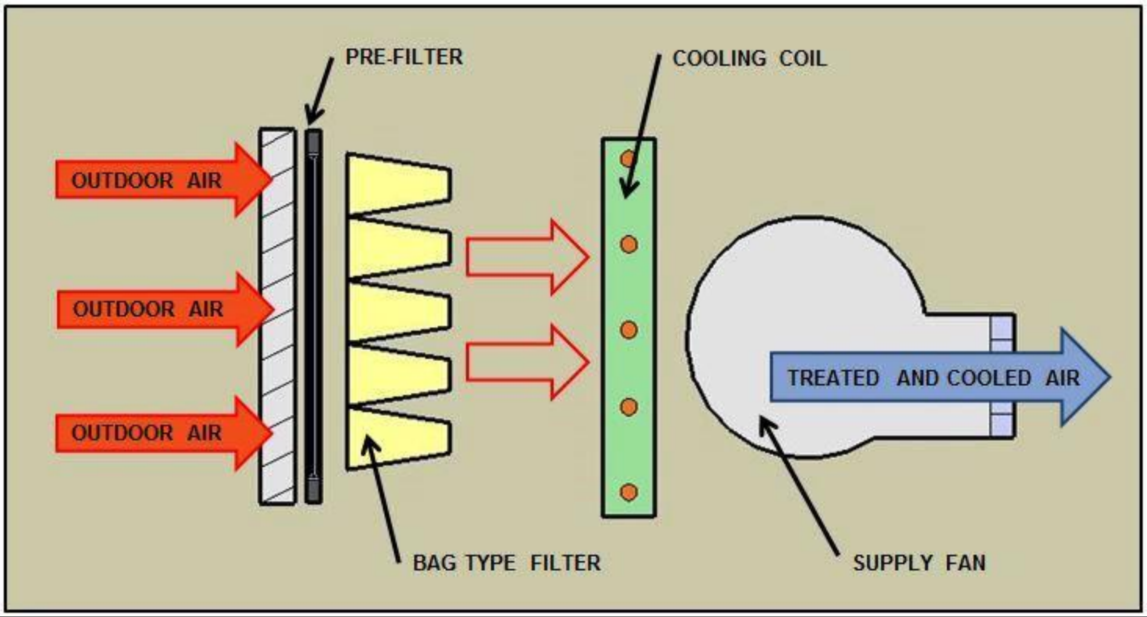


FIGURE 7 Diagram of a typical outdoor (fresh) air intake, filtering and cooling process

This form of outdoor / indoor exchange is mechanically controlled by a variety of means ranging from a simple by an on- off switch, a temperature/humidity sensor to a sophisticated Building Management System (BMS). A mechanically controllable system will have the most control in serving the three purposes of ventilation: a fresh supply of O_2, indoor contaminant removal from the space, and reducing unwanted infiltration.

Quantifying Ventilation

Ventilation volume in required in a building is calculated in several ways, including fresh air supply, room air change rate, and ventilation effectiveness.

The calculated basic ventilation rate should never be too large to cost extra energy for cooling or heating, nor too low to result in poor air quality. The most common calculation used is to check the basic requirement for fresh air supply. In a well-mixed enclosure of air, where the generation rate is steady, concentration level of a particular air specimen is proportional to the ratio of the ventilation rate over the strength of the source of the air specimen.
The equation below is the fundamental equation, which forms the basis of both CIBSE and ASHRAE guidelines: **(xxviii)**

Basic Ventilation Rate Equation: $Q = \frac{G(10^6 - C_i)}{E_v(C_i - C_o)}$

Where:
C_i – is the equilibrium concentration of the specimen [in $ppm\ or\ \mu gm^{-3}$]
C_o – is concentration level in the outdoor air [in $ppm\ or\ \mu gm^{-3}$]
Q – is the ventilation rate using outdoor air [in $\mu gs^{-1}\ or\ m^3 s^{-1}$]

G – is the generation rate of the specimen [in $\mu g s^{-1}$ or $m^3 s^{-1}$]
E_v – is the ventilation effectiveness

Fresh air supply rate, *Q*, normally outdoor air supply rate, is simply the total volumetric flow rate of the outdoor air into the room, with a unit of Liter per second (ls^{-1}). This variable is used in British Standards to specify a basic requirement of fresh air in a specific indoor space, for either passive ventilation, including both infiltration and natural ventilation or for mechanical ventilation.

Air change rate, *n*, is a measure quantifying how many times the indoor air has been completely replaced by the outdoor air with one hour duration. Its unit is air changes per hour (ACH). When the air change is due to the uncontrollable infiltration, this rate is noted as Infiltration Rate.

Conversion between the two key variables:

$$Q(l/s) = \frac{V(m^3) \times 1000 \times n(ACH)}{3600}$$

OR

$$n(ACH) = \frac{Q(l/s) \times 3600}{V(m^3) \times 1000}$$

Where:
V – is the net volume of the space **(xxix)(xxx)**

The most established method of calculating outside air requirements is the ventilation rate procedure of ASHRAE 62.1 standard. The procedure is fairly simple where depending on the space type each occupant has a prescribed l/s/person rate and the area has an l/s/m2 rate. For example an office space would require 2.5l/s/person plus 0.06 l/s/m.
In the GCC climate, very hot, humid, particulate and sometimes bacteria laden outdoor air is then brought into the interior space to be transformed through cooling to a level of human comfort. In this process the inherent water vapor in the warm air is de-humidified and the water siphoned off so that it to provide thermal comfort and prevent condensation that might cause microbial growth, while the air is additionally being ‘scrubbed’ clean of visually undetectable pollutants to become the healthy indoor air we continuously re-cycle and breathe 24 hours a day. Maintaining quality in this process represents a formidable challenge that will require increased efforts by all participants in the construction industry.

Controlling and Monitoring the Rate and Performance of Indoor Air Quality:
To calculate adequate indoor air quality for both natural and mechanical ventilated systems the majority of international building energy and / or sustainability regulations follow the ASHRAE Standard 62.1-2007.

In addition to that, CO_2 monitors should also be used to measure the effectiveness of the ventilation system in delivering outdoor air and to reduce the fresh air quantities during low occupancy periods. It should be made sure that the CO2 monitors are placed between 3 and 6 feet above the ground. **(xxxi)**

While controlling the fresh air quantities in a dedicated outside air system (DOAS) using CO_2 sensors and dampers in every space is fairly simple (though expensive) The control of fresh air quantities based on CO_2 monitoring is very challenging in a multi-zone recirculating system. ASHRAE research project 1547 which should be concluded next year is looking into these concerns.

As the 'lungs' of a building, heating, ventilation and air conditioning (HVAC) systems re-cycle indoor temperature and air quality. Design basics such as keeping a minimum distance between exhaust air and fresh air intakes and insuring that the building is under positive pressurization will assist in reducing unwanted infiltration that might cause condensation and bacterial growth.

Air contaminates may settle within the HVAC system to recirculate through a building. Sandstorms in the Gulf region increase dust concentrations, challenging the filters in a HVAC system. Consequently, the life span of these air filters is shortened, requiring more frequent cleaning or replacement. **(xxxii)** Routine cleaning of air ducts and cleaning and treating of cooling coils will also help to improve the effectiveness of a HVAC system and recirculation of air pollutants. HVAC maintenance companies should also review the application of antimicrobial products specifically designed for use in air condition systems to inhibit fungal growth.

HVAC systems, if not properly cleaned may contain mold, allergen, bacteria, viral and dust contaminates, such as lint, carpet fibers, construction dust, spores, fiberglass, asbestos, pollen, bacteria, rust, hair and human skin. Periodic inspections of the following HVAC system components are required to identify potential issues with indoor air quality:

FIGURE 8 – Listing of HVAC components where air and water borne particles and biological material can accumulate

HVAC System Component
Air Filter
Air Handler
Boiler stack
Cooling Tower
Condensation Pan
Dampers
Ducts
Exhaust Fan
Fan Coil
Filter Racks
Heating and Cooling Coil
Humidification and Dehumidification Equipment
Mixed Air Plenum and Outdoor Air Control
Mixing Boxes
Outdoor Air Intake
Plenum

Return Air System
Supply Fan

In addition to improving building ventilation systems and increasing outdoor air circulation, there are several steps that homeowners, building owners and school administrators can minimize indoor air pollutant sources. The following steps can further reduce or eliminate air pollutant exposure **(xxxiii)**

• Dust and clean regularly	• Use cleaning products according to manufacturer's directions
• Do not allow smoking indoors	• Control pests—close up cracks and crevices and seal leaks; don't leave food out
• Do not use candles, kerosene lamps, and incense indoors	• Separate storage areas from living areas
• Clean mold and fix water leaks	• Run bathroom, kitchen and laundry exhaust fans
• Keep pets out of bedrooms and off soft furniture	• Use allergen-proof mattress and pillow covers
• Periodically test for radon gas	• Use appliances that vent to the outside whenever possible.
• Do not to block air vents	• Monitor and adjust indoor humidity

Conclusion and Recommendations

- Reducing heat load can reduce energy loss, ACH rates and the risk of poor air quality. More incentives to passive design to reduce natural heat load by emphasizing features that reduce direct heat conduction (thermal bridging, orientation), radiant heat load (lower U values), high SRI values and convective gains (fixed and automatic controlled shading devices, less south and west glazing) should be created for passive design, the most cost-effective form of sustainable building.
- To combat the numerous natural factors that negatively affect air quality in the GCC region, programs for measuring the IAQ of existing building and during the construction of new buildings to promote high operational air quality should be expanded. Public awareness should also be promoted as a positive health initiative.
- HVAC systems have undergone many improvements in terms of energy efficiency; it is now time to increase industry focus on fresh air delivery, Indoor Air Quality monitoring and control as well as HVAC system hygiene.
- GCC codes have taken their initial performance guidelines from existing codes in moderate climate areas of Europe and the United States. The need to move gradually to foster acceptance is important; however, as better data records are kept, it is now possible to monitor the real achievable rates of building envelope permeability in the region. The large difference between unwanted Envelope Permeability outdoor /indoor air

exchange rates and the rates of required Fresh Air Change should be further studied to ultimately develop regional acclimatized standards.

- There should be more regional coordination of the various 'Green Code' initiatives and the numerous groups and organizations that have spurred the growth of ecological and resource conservation in the MENA countries. Regional Sustainable building should also increase focus on the health aspects of sustainable practice. Interacting with health professionals and officials on common areas of concern will enhance and focus the effectiveness of these efforts.
- In the GCC climate, very hot, humid, particulate and sometimes bacteria laden outdoor air is a challenge that engineering and architectural professionals in moderate climates such as the UK and the US normally do not deal with on a constant basis. Cooling the raw harsh air to a level of human comfort, de-humidifying it to provide thermal comfort and preventing the harmful effects of visually undetectable pollutants to create the healthy indoor air we continuously re-cycle and breathe 24 hours a day is a process that represents a formidable challenge. Meeting that challenge will require increased efforts and more interaction by all participants in the construction industry.

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