HEALTH AND INDOOR AIR QUALITY – A GROWING CONCERN

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ABSTRACT

In recent years, the attention of environmental researchers has been focused on indoor air pollution, as a result of reports of symptoms or specific diseases that occur mainly in airconditioned and mechanically ventilated buildings. Studies have proved that level of contaminants in the indoor air can be often several times higher than outdoor air. This combined with the fact that people tend to spend 90% of their time indoors, proves the point that a person's major source of exposure to airborne contaminants can be indoors.

Poor indoor air quality leads to an increased incidence of health related symptoms, which in turn can lead to an increase in absenteeism and a loss of productivity. Some of most common symtoms can be related to "Sick Building Syndrome".

In hospitals and nursing homes, 100% fresh air is the norm. If the same airconditioned air carrying germs, bacteria and viruses is recirculated the Indoor air environment can lead to more sicknesses and health problems than curing them.

"The solution to the problem of pollution is dilution" or increased ventilation, runs contrary to the energy conservation guidelines being followed by airconditioning designers. In hospitals and nursing homes, the ventilation standards require 100% fresh air and higher number of air changes per hour. The new standards and guidelines being dictated by ASHRAE standard 62-1989 for IAQ, establishing generally 20 cubic feet per minute (cfm) per person in workplaces as recommended outdoor air requirement, has set new challenges for equipment manufacturers to meet the needs of the building owners and designers for matching the IAQ requirements with energy conservation needs.

This paper examines the above issues in greater detail and also how 'enthalpy wheels' have effectively provided the solution for improving IAQ by curtailing energy costs and providing a chance for creating a healthy environment.

SHIFTING FOCUS ON INDOOR AIR QUALITY

The world focus has shifted from the environment to 'Invironment'. This is a new terminology, being used increasingly to focus on the Indoor Air Quality (IAQ) and its effect on human health. While the outdoor environment continues to be of concern, the indoor environment is receiving increased attention as more information has become available on the presence and effect of indoor contaminants.

Over the last 15 years, our knowledge of environmental health and air quality issues has increased dramatically. Today, although still not totally accepted by the medical profession, as a result of increasing exposure to a wide range of chemicals at work, home, and even hospitals there appears to be a growing population of chemically hypersensitive individuals. Growing awareness of the stressful effects of life long exposure to such chemicals, noise, mortality effects of living near nuclear power plants and/or high voltage lines or even the use of electric heated blankets may soon lead physicians to ask about such exposures when taking a new patient's history.

WHAT IS IAQ?

Indoor Air Quality refers to the nature of the conditioned (Heat/cool) air that circulates throughout space/area where we work and live, that is the air we breathe during most of our lives.

IAQ refers not only to comfort which is affected by temperature, humidity and odors but also to harmful biological contaminants and harmful chemicals present in the conditioned space.

The origins of poor IAQ issue are well known. An emphasis on energy conservation after the oil embargo of 1970s resulted in tighter buildings with recirculated air for building ventilation and minimum amounts of fresh air being brought into commercial buildings. This minimized the amount of air to be heated or cooled and hence conserved on energy.

However, the combination of "tight" buildings with little or inadequate fresh air ventilation, produced an indoor environment with relatively high levels of chemical contaminants, bacteria, fungi and dust. It is a well recognised fact now, that indoor air in an airconditioned/mechanically ventilated space can be several times more polluted than outdoor air. The larger concentration of indoor air pollutants, combined with the fact that most people spend 85 to 90% of their time indoors, make them susceptible to illnesses related to these airborne contaminants.

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POLLUTANTS CONTRIBUTING TO POOR IAQ

Sulphur, nitrogen dioxide, carbon monoxide produced by combustion and emission, high pollen counts, pesticides, chemical compounds, all contribute to outdoor pollution. Indoor air will contain all of the pollutants of the outdoor air as well as those generated indoors by the occupants and their activities.

The indoor air contaminants which can be hazardous to health include Environmental Tobacco Smoke (ETS), formaldehyde, radon, asbestos, VOCs emanating from solvents, paints, varnishes, carpets, pesticides causing long term and short term illnesses. Biologicals like bacteria, viruses, fungus exhaled by humans or due to presence of high humidity, directly affect the health of the occupants causing respiratory infections, Tuberculosis, measles, smallpox and staphylococci are transmitted by ventilation systems in hospitals. Bacterial aerosols are incubated in toilets, water machines and carpets and are distributed by cooling equipment. Indoor allergens include pollen, mold, fungi, hair, insect parts and chemical additives causing lung and skin diseases. Odours and dust cause significant discomfort, feelings of unpleasantness.

In a conditioned space, since free passage of air is limited, pollutants tend to accumulate resulting in higher concentration of some contaminants than outdoor ambient air. Most of the pollutants that we find indoors can be sourced to commonly found items around us.

Listed below are some common pollutants and their effects on health

Pollutant	Source	Health effect
Environmental Tabacco Smoke (ETS)	Cigarette + Smoke exhaled by smoker	Leading cause of lung cancer, headache eye irritation, wheezing cough. Asthma and bronchitis in children.
Bacteria, Fungus, Mold, Mildew	Wet or moist walls, ceilings carpets and furniture, poorly maintained ACs.	Allergic reactions, infections illnesses e.g. influenze, measles and chicken pox, eye nose throat irritation etc.
Carbon Monoxide (CO)	Environmental tabacco smoke.	Fatigue, chest pain in heart patients, impaired vision, headaches, dizziness, nausea and respiratory irritation.
Formaldehyde	Pressed wood products made by using adhesives, ETS, drapes other textiles and glues.	Eye, nose and throat irritation, wheezing, coughing, skin rash and severe allergic reactions
Volatile Organic Compounds(VOCs)	Paints, paints strippers and other solvents, wood preservatives, carpets, varnishes and cleaning and disinfecting agents.	Eye, nose and throat irritation, headaches, loss of co-ordianation, nausea, damage to liver, kidney and central nervous system.
Asbestos	Fire proofing material, floors and tiles.	The long term effects are chest and abdominal cancer and lung infections. Asbestos induced lung cancer.

The consequences of poor 'Indoor Air Quality' which a health professional must concern himself with -

a. the effect of poor IAQ on the health of the individual at his workplace or house. Physicians need to be aware of these health hazards when taking a new patient's history to make a proper diagonosis.

b. the effects of poor 'Indoor Air Quality' in the health care facility such as the hospital and nursing home and consequential damage to the already ailing patient.

EFFECTS OF POOR IAQ ON HEALTH OF INDIVIDUALS AT HIS WORKPLACE

THE SICK BUILDING SYNDROME (SBS)

In recent years, the attention of environmental research has been focussed on indoor air pollution as a result of reports of symptoms or specific diseases that have been identified among the occupants of airconditioned buildings, by a phenomenon called 'Sick Building Syndrome'.

"Sick Building Syndrome" is a term that describes the presence of acute non-specific symptoms in the majority of the people, caused by working in buildings with an adverse indoor environment. It is a cluster of complex irritative symptoms that include irritation of the eyes, blocked nose and throat, headaches, dizziness, lethargy, fatigue, irritation, wheezing, sinus congestion, dry skin, skin rash, sensory discomfort from odours, and nausea.

Health effects from indoor air pollutants fall into two categories those that are experienced immediately after exposure and those that do not show up until years later.

The lung is the most common site of injury by air borne pollutants. Acute effects, however may also include non-respiratory signs and symptoms, which may depend upon toxicological characteristics of the substances and host of related factors.

Immediate effects, in addition to the signs and symptoms already listed, may also include eye and/or nasopharyngeal irritation, rhinitis or nasal congestion, inability to concentrate and general malaise - complaints suggestive of a host of common ailments, some ubiquitous and easily communicable. The key factors are commonalty of symptoms among building occupants when the individuals are in the building.

'Sick building syndrome' should be suspected when a substantial proportion of these spending extended time in a building (as in daily employment) report or experience acute on site discomfort. It is important however, to distinguish SBS from problems of building related illness. The latter term is reserved for situations in which signs and symptoms of diagnosable illness are identified and can be attributed directly to specific airborne building contaminants. Legionnaire' disease and sensitivity pneumonitis, for example are building related illnesses.

Another diagonistic label of multiple chemical sensirtivity (MCS) also referred to as "chemical hypersensitivity" or 'environmental illness is being applied increasingly. Persons with MCS are said to suffer multisystem illness as a result of contact with or proximity to, a spectrum of substances including airborne agents.

The health professional should look for key signs and symptoms to help determine the cause of the health problem.

Diagnostic Quick Reference

Signs and Symptoms	Environmental Tobacco Smoke	Other Combustion	Biological Pollutants	Volatile Organics	Heavy Metals	Sick Bldg. Syndrome
Respiratory						
Rhinitis, nasal Congestion	*	*	*	*		*
Esistaxis				*[1]		
Pharyngitis, Cough	*	*	*	*		*
Wheezing, Worsening Asthma	*	*		*		*
Dyspnea	*[2]		*			*
Severe lung Disease						*[3]
Other						
Conjunctival Irritation	*	*	*	*		*
Headache or Dizziness	*	*	*	*	*	*
Lethargy, Fatigue, Malaise		*[4]	*[5]	*	*	*
Nausea, Vomiting, Anorexia		*[4]	*	*	*	
Cognitive impairment, Personality change		*[4]		*	*	*
Rashes			*	*	*	
Fever, chills			*[6]		*	
Tachycardia		*[4]			*	
Retinal hemorrhage		*[4]				
Myalgia				*[5]		*
Hearing loss				*		

[1]Associated especially with formaldehyde. [2]In asthma. [3]Hypersensitivity pneumonitis' Disease. [4]Particularly associated with high CO levels. [5]Hypersensitivity pneumonitis, humidifier fever. [6]With marked hypersensitivity reactions and Legionnaires' Disease.

The economic consequences of the sick building syndrome and building related illnesses relate to decreased productivity, absenteeism and the cost of providing the correct environment.

While there is no proof that maximum comfort leads to maximum productivity, there is ample evidence that an improved environment decreases worker complaints and absenteeism, thus indirectly enhancing productivity.

SBS in buildings may be due to a variety of causes like:

* Inadequate maintenance of the HVAC system, which becomes a source of contamination.
* Increased load (occupancy and activities) than designed.
* Inadequate fresh air/ventilation.
* Poor circulation or badly placed vents to prevent outside air reaching the occupants.
* Improperly located outdoor vents bringing in contaminanted air from automobile exhausts or restrooms.

However, poor IAQ is generally associated with improperly managed HVAC systems and inadequate ventilation. For each of the two effects of poor health and loss of productivity, adequate amounts of fresh air and appropriate ventilation can address the problem adequately.

THE IMPORTANCE OF IAQ IN HOSPITALS/NURSING HOMES

Nowhere, is the importance of IAQ as critical as in Hospitals and health care facilities. Continual advances in medicine and technology necessitate the airconditioning of hospitals and medical facilities. Hospital airconditioning assumes a more important role than just the promotion of comfort. In many cases, proper airconditioning is a factor in patient therapy in some instances, it is the major treatment. However the relatively high cost of air conditioning, has led to inadequate and improperly designed systems with not enough care to factor in specific requirements for ventilation, filtration and cross contamination.

TRANSPORT OF INFECTION SOURCES AND AIR QUALITY IN A HOSPITAL

The basic infection sources in a hospital are :

Bacterial Infection - Examples of bacteria that are highly infectious and transported within air or air and water mixtures are Mycobacterium tuberculosis and Legionella pneumophila (Legionnaire's disease). Since bacteria is normally present in colony forming units, they are usually taken care of by particulate air filters (HEPA), however droplets or infectious agents of less than 5 micron size or less can remain in the air indefinitiely.

Viral Infection - Examples of viruses that are transported by and virulent within air are Varicella (chicken pox/slengles), Rubella (German measles) and Rubeola (regular measles). Epidemiological evidence and other studies indicate that many of these airborne virus are submicron in size thus there is no known method to effectively eliminate 100% of the viable particles. Therefor, isolation rooms with appropriate ventilation are the primary means to prevent the spread of airborne viruses in the hospital environment.

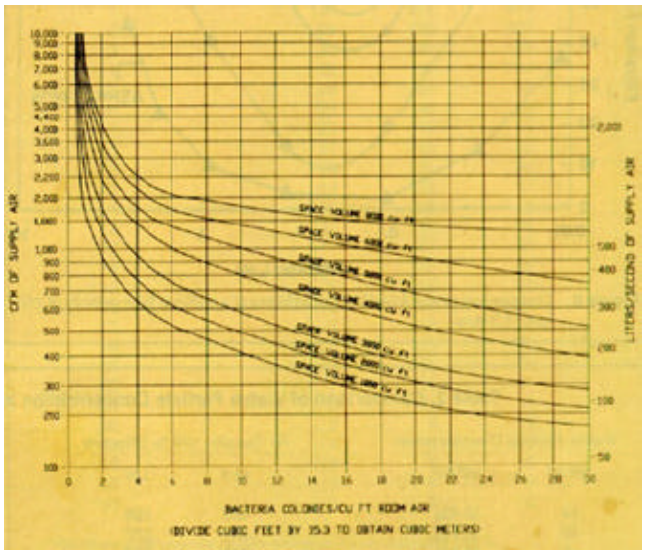
Molds - Evidence indicates that some molds such as Aspergillis can be fatal to advanced leukemia, bone marrow transplant and other immunocompromised patients.

Temperature and Humidity play a vital role as they can inhibit or promote the growth of bacteria and activate or deactivate viruses. Some bacteria such as legionella pneumophila are basically water borne and survive more readily in a humid environment.

AIR QUALITY - A KEY FACTOR

The advent of multidrug-resistant tuberculosis (TB), the increasing human immunodeficiency virous (HIV) population have all focussed awareness on the need to modify hospital ventilation design techniques. These factors have added greater urgency to effective sepsis control.

If outdoor air intakes are properly located and areas adjacent to outdoor air intakes are properly maintained, outdoor air, in comparison to room air is virtually free of bacteria and viruses. Infection control problems frequently involve a bacteria or viral source within a hospital. Ventilation air dilutes the viral and bacterial contamination within a hospital. If ventilation systems are properly designed, constructed and maintained to preserve the correct pressure relations between functional areas, they remove airborne infectious agents from the hospital environment.



No area of the hospital requires more careful control of the aseptic condition of the environment than does the surgical suite. minimum outdoor air changes per hour in the surgery and critical care, typically in the **operating rooms** is 15, with no recirculation of air. Ventilation with 100% fresh air is the only means to keeping the airborne organisms contamination low.

Postoperative recovery rooms used in conjunction with the operating rooms, should be maintained at a temperature of 75°F and a relative humidity between 50 and 60%. The residual anesthesia odor sometimes creates an odor problem in recovery rooms, ventilation is important and a balanced air pressure relative to the air pressure of adjoining areas should be provided.

In protective isolation units, immunosuppressed patients (including bone marrow or organ transplant, leukemia, burn and AIDS patients) are highly susceptible to diseases. An air distribution of 15 air changes per hour is recommended. The sterile air is drawn across the patient and returned near the floor at or near the door to the room.

In cases where the patient is immunosuppressed but not contagious, a positive pressure should be maintained between the patient room and adjacent area.

Other areas which require high rates of ventilation are Radiology department, laboratories, infections disease and virus laboratories, autopsy rooms and animal quarters.

MANAGEMENT AND IMPROVEMENT OF AIR QUALITY IN HOSPITALS

Air quality can be improved in hospitals by designing systems that provide air virtually free of dust, dirt, odours, chemical and radioactive pollutants, bacteria, virus and humidity buildup. Designers while planning airconditioning systems need to keep these design cirteria in mind -

(1) the need to restrict air movement in and between the various departments

(2) **the specific requirements for ventilation and filtration to dilute and remove contamination in the form of odour, airborne micro-organisms and viruses and hazardous chemicals and radioactive substances**

(3) the different temperature and humidity requirements for various areas and

(4) the design sophistication needed to permit accurate control of environmental conditions.

Though design specification regarding other aspects are adhered to, designers tend to compromise and accept substantial recirculated air to conserve on energy; leading to air quality problems.

There is increasing need to bring about more awareness in
1. Health Professionals.
2. AC&R engineers.
3. Equipment Manufacturers,

on the very important aspect of increased ventilation standards for mitigation of airborne pollutants. The focus of all designers have to fundamentally shift to this all important aspect of new hospital ventilation design strategies.

Air Cleaning Options

There are basically two ways in which air quality can be improved in a hospital

(1) Filteration
and (2) Ventilation

A variety of filters and aircleaning equipments are available in the market. Ionizers and ozone genarators, mechanical filter air cleaners, electronic air cleaners (e.g. electrostatic precipitators) and hybrid air cleaners are a few.

Ion generators act by charging the particles in a room so that they are attracted to walls, floors, tabletops. In some cases these devices contain a collector to attract the charged particles back to the unit. While ion generators remove

small particles from the indoor air, they do not remove gases, odours or allergens.

Ozone, a lung irritant is produced indirectly by ion generators and electronic air cleaners and directly by ozone generators. Under certain use conditions ion generators and other ozone generating air cleaners can produce levels of this lung irritant significantly above levels thought harmful to human health.

Generally speaking, air cleaners are not appropriate single solutions to indoor air quality problems but can be useful as an adjunct to effective source control and adequate fresh air ventilation. Air cleaning alone cannot adequately remove all pollutants typically found in indoor air.

However it has been seen that it is the **increased fresh air ventilation** which is responsible for mitigating the indoor air pollutants.

"THE SOLUTION TO POLLUTION IS DILUTION"!

Increased fresh air ventilation is the answer.

The only solution to mitigate the unacceptable levels of airborne pollutants in the hospital are: **addressing the source of pollution and addressing the level of contaminants in the air.** These may be referred to as '**source control'** and '**removal'** respectively.

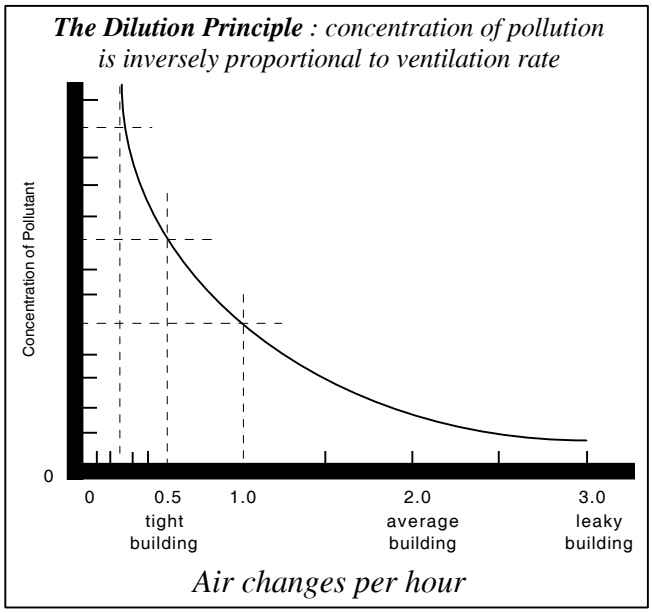
Source control, though the preferred approach, may not be often practical. Source control measures are pollutant specific and may include use of low formaldehyde emitting materials, banning of cigarette smoking, prevention of radon entry through sealing of foundations, eliminating use of asbestos and storing of paints and chemicals outside the occupied space. Controlling relative humidity will prevent microbial contamination.

Removal of contaminants from a building or reducing its concentration within a hospital can be accomplished by passive or active fresh air ventilation.

Passive ventilation refers to air exchanged through doors, windows or other openings by natural forces. In most airconditioned buildings, these openings have been reduced to the minimum to conserve energy.

Active ventilation systems provide continuous ventilation to which passive ventilation may add but not subtract when pollutants are evenly mixed throughout a space and the source rate is constant; the concentration of airborne pollutants will be inversely proportional to the ventilation rate, that is, doubling the ventilation will halve the concentration!

An existing ventilation system which is inadequate because of design flows, poor maintenance or expanded use of a building is often associated with poor indoor air quality. Mitigation can often require redesign or maintenance. In cases where the outdoor air ventilation provision of an HVAC system is not being used, the remedy is obvious - increase ventilation.



The table covers current ventilation standards for comfort, sepsis and odor control in areas of acute care hospitals that directly affect patient care.

Reproduced below are the recommended ventilation rates for Hospitals, Nursing and Convalescent Homes, under the ASHRAE 62-89 standard.

Application	Estimated maximum Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/ person	L/s person	cfm/ ft²	L/s m³
Patient room	10	25	13		
Medical procedure	20	15	8		
Operating rooms	20	30	15		
Recovery and ICU	20	15	8		
Autopsy rooms				0.50	2.50
Physical Therapy	20	15	8		
Correctional Facilities					
Cells	20	20	10		
Dining halls	100	15	8		
Guard stations	40	15	8		

Source : ASHRAE Standard 62-1989

MEASUREMENT OF IAQ/VENTILATION RATE . . . . CO_2 AS THE SURROGATE INDEX

In order to evaluate excessive indoor air pollution and its health effects, it is important to identify which pollutants are present in a room or building and to determine how the levels of each vary with the time. Monitors are available for particulates and a few gases such as radon, formaldehyde, nitrogen dioxide, sulphur dioxide and carbon monoxide; however analysis of each can be complex, costly and time consuming. In some situations the source of contamination may be unknown and testing for a broad spectrum of possible pollutants may be required.

Although it is extremely expensive and difficult to detect or measure the indoor air contaminants, CO_2 (carbon dioxide)

has been recognised by ASHRAE (American Society for Heating, Refrigeration and Airconditioning Engineers) as the surrogate ventilation index or the only measurable variable.

Carbondioxide levels in an airconditioned room is a good indicator of occupancy and ventilation rate within a space.

CO_2 by itself is not considered an indoor air contaminant. Humans are the major source of CO_2. As people exhale CO_2, they also exhale and give off a wide range of 'bioeffluents'. These bioeffluents include gases, odours, particulate, bacteria, viruses. When these bioeffluents are allowed to build up in space, due to poor ventilation, occupants complain of fatigue, headache and general discomfort. The assumption is that if there is sufficient ventilation to remove the human generated contaminants, there will be no discomfort.

Outside levels of CO_2 are relatively constant and range between (350 to 600 ppm); inside levels will never be below the outside level. The amount of CO_2 in the space can give us an indication of the number of persons within the space. Therefore, the concentration of CO_2 in a space can provide an indication of the actual ventilation rate per person within the space. If the CO_2 levels are higher than 1000 ppm (parts per million), then it is an indication that not enough outdoor air is coming in to dilute the CO_2 level. Therefore the indoor air is being recirculated and the levels of the other pollutants in the enclosed space must be high.

ENERGY MANAGEMENT IN HOSPITALS AND IAQ WITH ENERGY/HEAT WHEELS

Higher fresh air ventilation needs translate into higher outdoor air changes per hour, which means more airconditioning loads and higher capacity plants to be installed. This leads to higher first cost and higher operating costs.

Infact, health care is an energy intensive, energy dependent enterprise. Hospital facilities are different from other structures in that they operate 24 hours a day year round, require sophisticated backup systems in case of utility shutdowns, use large quantities of outdoor air to combat odors and dilute micro organisms, and must deal with problems of infection and solid waste disposal.

Hence effective management of energy systems becomes imperative.

Increasing ventilation rates translates into two ways - An improved indoor environment and significant higher utility bills for the owners.

The solution is the use of energy recovery devices of which the energy/heat wheel is the most appropriate.

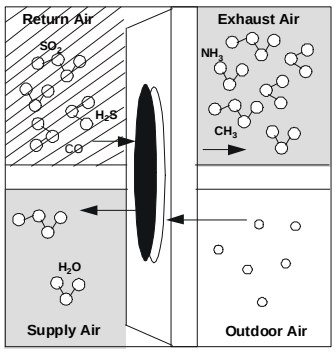
HOW DOES THE ENERGY/ENTHALPY WHEEL WORK?

The energy wheel preconditions fresh outside air before it is introduced to a building. The system can easily be tapped into an existing ventilation system. A portion of the air that would normally be recirculated through the system is exhausted through the wheel and fresh air is introduced into the building in its place. Operating in virtually any climate zone, a single desiccant wheel operated with just a small motor to rotate the wheel can deliver fresh air on a year round basis that is generally within 3-7 degrees and 10% RH of inside conditions, regardless of what outside conditions are (without any type of mechanical cooling or heating). The cost to provide high levels of fresh air ventilation becomes minimal compared to the normal heating cooling requirements of the building. The potential benefits are numerous.

* Current standards for outside air ventilation can be met or exceeded with minimal energy cost impact on the building.
* Incoming outside air is dehumidified by the desiccant wheel, allowing the rest of the ventilation system to run dry. As a result, indoor humidities are maintainable well below the conditions that would favour the growth of mould, mildew and other microbial contamination.
* The need for cooling capacity that normally would be required to dehumidify and cool outside air is eliminated. This is typically 30 to 50% of total system capacity. **In most cases, the cost of the energy wheels is almost less than the cooling capacity it is replacing.** The first cost of a building's cooling system can actually be reduced with a wheel system.

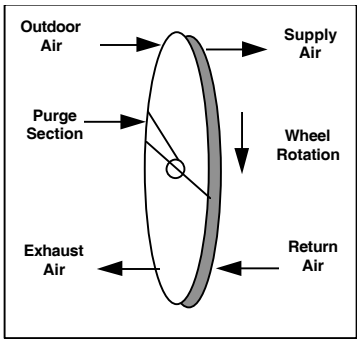
ADDITIONAL BENEFITS OF THE WHEEL FOR HOSPITAL APPLICATION

The new energy wheels have a coating which provides selective adsorptions which eliminates cross contamination of bacteria and airborne contaminates.



In hospitals, clean rooms and animal houses requiring stringent control of IAQ and 100% fresh air, these wheels provide the best options. The wheels are coated with 3A/4A (molecular sieve) as the desiccant which allows even the smallest diameter pollutants to blow over because the pore size of the desiccant allow only molecules smaller than 3A/4A in diameter - 5000 smaller than the diameter of the

human hair to pass into the fresh air supplies. As a result the contaminations remain in the exhaust air stream.

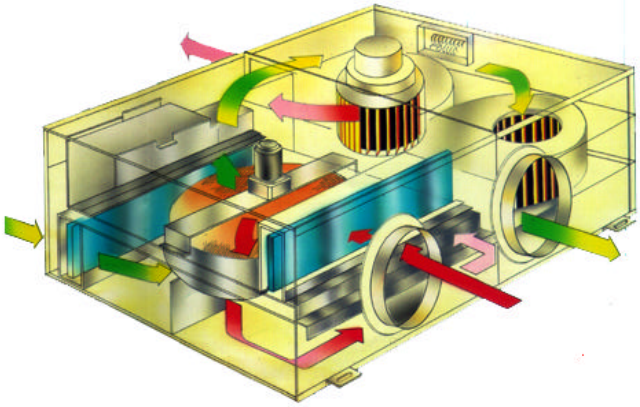


In built purge sector eliminates cross contamination. The purge sector flushes out the flutes before they enter the supply air side.

INTEGRATING ENERGY WHEELS IN HVAC SYSTEM

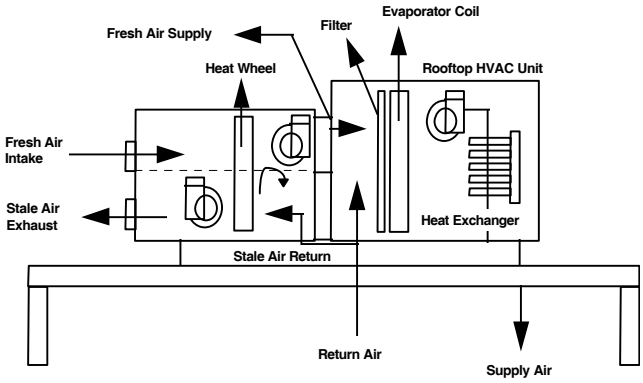
The energy wheels are available in several sizes and configurations and are being integrated in small, compact standardized units for installation in nursing homes and clinics as unitary systems and are being sold as energy saving fresh air preconditioners to handle smaller loads.

Typical Unitary Energy Saving Preconditioner (ESP)



Larger energy wheels are being integrated in packaged AHUs or designed in modular systems for integrating into HVAC systems to cater to larger fresh air loads for hospitals, animal laboratories and hotels.

Typical Installation : 'Heat Recovery Wheel Integrated with HVAC for New Areas



CONCLUSION :

Indoor air quality is an evolving issue. Though indoor air quality measurement and monitoring is often difficult, with few standard methods available; neverthless, substantial evidence exists that indoor air pollution has impact on the health. Effects of hazardous substances found in indoor air range from the irritating to the deadly, depending on the substance, its concentration and length of exposure. However, 'clinical ecology' a branch of medicine involving multiple chemical sensitivity to substances in their work environment is drawing the attention of health professionals.

It is the need of the day, for health professionals to understand the health effects arising from poor indoor air quality and to understand how and what factors affect the indoor air quality in hospitals and nursing homes and what could be done to improve the air quality!

REFERENCES

* ASHRAE Standard 62-1989.
* 'Application guide for CO_2' - Telair Systems Inc, USA.
* 'Eco-Fresh' - Technical data, Arctic India Engineering.
* HVAC Systems and Equipment - ASHRAE Handbook.
* Indoor air pollution-An introduction for health professionals-EPA.
* Hospital Sepsis Control and TB Transmission by Edgar L. Galson.
* 1995 ASHRAE Handbook - HVAC applications.
* New Ventilation Standards for Indoor Air Quality (IAQ) *Vs* Energy Conservation : Enthaly Wheel meet the challenge **by Deepak Pahwa,** B.Sc. Engg**.,** ***Member ASHRAE.***