

Airflow Modeling: Efforts to Find the Better Models for Building Air Quality Simulation

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Airflow Modeling: Efforts to Find the Better Models for Building Air Quality Simulation

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Airflow Modeling: Efforts to Find the Better Models for Building Air Quality Simulation.

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Abstract. All combustion sources, such as motor vehicle, industrial combustion processes, burning, cooking, heating, and tobacco smoking, generate large quantities of fine (aerodynamic diameter smaller than 2.5 micro-meter) and ultra-fine (smaller than 0.1 micro-meter) particles. Smaller particles can penetrate deeper into the respiratory tract and therefore have a higher potential to induce health effects than larger particles.

Suspended particulate matter can serve as nuclei and carriers for airborne viruses and bacteria, resulting in the spread of diseases. In addition, fine particles themselves can deposit in the lungs and cause respiratory diseases. As people spend about 90% of their lifetime indoors, indoor particulate matter can have great impact on human health. Thus, a good understanding of particle transport (included in dynamics flow) is crucial for creating healthy indoor environments.

In this paper, more than four model simulation of indoor airflow for building is reviewed. Hope fully, this help decisions maker have many consideration to improve or manage airflow for building. This is an effort to improve working environment in factory that seems to be severely affected by particulate matter.

Keywords: *particulate matter, airflow, building, simulation*

1 Introduction

Health problems related to the environment have become a major source of concern all over the world. The health of the population depends upon good quality air, water, soil, food and many other factors, can be analyzed in terms of the costs, as a part of consequences of failure in Risk Analysis. The environmental consequences of an event can also have other serious consequences, which affect company's reputation. It's needed to establish measures that can eliminate or considerably reduce hazardous factors from the human environment to minimize the associated health risks. The ability to achieve these objectives is in great part dependent on the development of suitable experimental, modeling and interpretive techniques, which will allow a balanced assessment of the risk involved as well as suggesting ways in which the situation can be improved. The interaction between environmental risk and health is often complex and can involve a variety of social, occupational and lifestyle factors. This emphasizes the importance of considering an interdisciplinary approach in related with environmental indoor health.

To raise efforts for promoting healthy working-environment, sustainable management of building and or factory that must have indoor room, this paper will present deep supporting information that needed to consider mainly about indoor air quality's factors. Primary goal of this paper is to present existing information in ways compatible with other engineering disciplines, then to



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contribute to the body of knowledge itself in order to advance our understanding of controlling Particulate Matter that is a part of contaminants in the indoor air environment.

This paper seeks to bridge the disciplines of engineering and industrial hygiene. Engineering knowledge contains the fundamental relationships needed to describe the movement of contaminants in the indoor environment; industrial hygiene contains knowledge that time and concentration to conditions injurious to health. Both disciplines are needed to create quantitative relationships that become criteria upon which products, systems, and process can be designed.

To help summarized the information provided in this paper, inclusion of four model simulation of indoor airflow for building is reviewed to help gathering prediction the velocity and pollutant concentrations at arbitrary points inside a building or room. This paper is organized into eight sections beginning with fundamental concept of risk, the main factors affecting contaminant dispersion, characteristic of Indoor air environment, aerosol as one kind of particulate matter and contaminants, impact of aerosol, type of indoor air flow and standard that related to indoor air quality, and the respiratory system; ending with the elements of future computational methods that possible to used to predict contaminant particles transport in the vicinity of process equipped with industrial ventilation systems, that currently more then four Simulation in the world-internetworking-advanced-search-based.

2 Fundamental Concept of Risk (Cairo et. al, 1999)

A typical dictionary defines risk as the possibility of loss or injury. It implies that risk has two main components: the probability of some event occurring and the negative consequence if it occurs. Thus, to analyze risk we should be able to estimate these two factors. Boehm (1989) translated this definition into the fundamental concept of risk management: the risk exposure, sometimes called risk impact.

$$RE = P (OU) \times L (UO) \quad (1)$$

Where RE means risk exposure, P(UO) expresses the probability of an unsatisfactory outcome, and L(UO) means the loss to the parties affected if the outcome is unsatisfactory.

Usually the perception of risk is higher for those items over which one have little or no control. However, the importance of the risk factors might be considered as some combination of risk frequency (that is, how likely it is that the risk will occur) and risk impact (such as, how serious a threat the risk represents if it does occur). In considering risks you must also consider their perceived level of control. This represents the degree to which the project manager perceived that their actions could prevent the risk from occurring. Most of the probable risks or threats to projects can be reduced or avoided using an appropriate methodology. It can also be complemented with approximative methods, which can provide enough information to support risk management decisions.

Risk-reduction is a fundamental part of project management in software and knowledge engineering. Software risk management is important because it helps people to avoid disasters, rework, and overkill, it also stimulates win-win situations on software projects (Boehm, 1989).

We should be aware that by avoiding or reducing the most significant risks, managers make more informed decisions, we obtain better outcomes, and hence the project will have a higher

probability of success. Again Boehm (1988) suggests to use a software risk management plan, which consists of five steps:

- Identify the project's top risk items.
- Present a plan for resolving each risk item.
- Update list of top risk items, plan, and results monthly.
- Highlight risk-item status in monthly project reviews.
- Initiate appropriate corrective actions.

Successful management of a project leads to control. Control leads to quality. Quality leads to satisfied customers. And we know customers are the final arbiters of a product or service.

3 Indoor Air Environment and Standards

From Gant., et al. (2006) we found the latest information about types of indoor air flow and the standards which relate to indoor air quality. The following general classification into jet (or momentum) controlled flows and buoyancy controlled flows is proposed by Etheridge & Sandberg (1996) and Linden (1999). This classification covers both forced and naturally-ventilated spaces. In jet-controlled flow, air is introduced into the space using high-velocity devices. The jets of air cause enhanced mixing and dilution of contaminants. When cool air is supplied from high-level devices such as ceiling-mounted diffusers or grilles, the air speed in the occupied zone is generally higher than when the room is supplied with the same inlet flow rate under isothermal conditions. When buoyancy forces are sufficiently strong (i.e. when the temperature difference between supply and room air is sufficiently large), the cold jet separates from the ceiling and falls into the occupied zone. In buoyancy-controlled indoor environments the air motion is controlled by heat sources in the room and fresh air is usually supplied at relatively low-velocity. Four supply/extract configurations can be considered: Air supply at low level and extract at high level (displacement ventilation); A single opening at high level; A single opening at low level; A single side opening.

From ASHRAE Standard 62, acceptable indoor air quality defines as air in which there are no known contaminants at harmful concentrations and where the substantial majority of people (80% or more) do not express dissatisfaction. The definition covers occupant comfort, odors and harmful levels of contaminants. Examples of common contaminants include: carbon dioxide, carbon monoxide, microorganisms, viruses, allergens and suspended particulate material. These contaminants are introduced into indoor spaces by human and animal occupancy, by the release of contaminants in the space from furnishings, accessories and/or processes taking place in the space, or from the supply of contaminated fresh air. Poor indoor air quality may be discernible by occupants as visible suspended particulate matter in the air or odors, or may be discernible only by sensitive measuring devices.

Below is a summary of sources of information on contaminants, safe occupational exposure levels, recommended practices and regulations:

- HSE
 - COSHH Regulations: Approved Code of Practice and Guidance (<http://www.hse.gov.uk/coshh/>)
 - COSHH Essentials: Easy Steps to Control Chemicals (<http://www.coshh-essentials.org.uk/>)
 - EH40/2005: Workplace Exposure Limits
 - Advisory Committee on Dangerous Pathogens publications (<http://www.hse.gov.uk/aboutus/meetings/acdp/index.htm>)
- UK Building Regulations

(http://www.adpm.gov.uk/stellent/groups/adpm_buildreg/documents/sectionhomepage/adpm_buildreg_page.html)

- Part D: Toxic Substances (for insulation materials)
- Part F: Ventilation
- Part J: Combustion Appliances and Fuel Storage Systems
- Part L: Conservation of Fuel and Power
- UK Health Protection Agency
(<http://www.hpa.org.uk/>)
- UK Department for Environment, Food and Rural Affairs (DEFRA)
(<http://www.defra.gov.uk/environment/airquality/index.htm>)
- Committee on the Medical Effects of Air Pollutants (COMEAP) – part of the UK Department of Health (<http://www.advisorybodies.doh.gov.uk/comeap/index.htm>)
- CIBSE
 - Guide B2: Ventilation and Air Conditioning
- European Directives (<http://europa.eu.int/comm/environment/air/>)
 - Framework Directive 96/62/EC (outdoor air quality)
 - Daughter Directive 1999/30/EC
- ASHRAE
 - HVAC Applications Chapter 45: Control of Gaseous Indoor Air Contaminants
 - Fundamentals Chapters 9: Indoor Environmental Health
 - Fundamentals Chapter 12: Air Contaminants.
- U.S. Occupational Safety & Health Administration (OSHA)
- U.S. Environment Protection Agency (EPA) (<http://www.epa.gov/air/>)

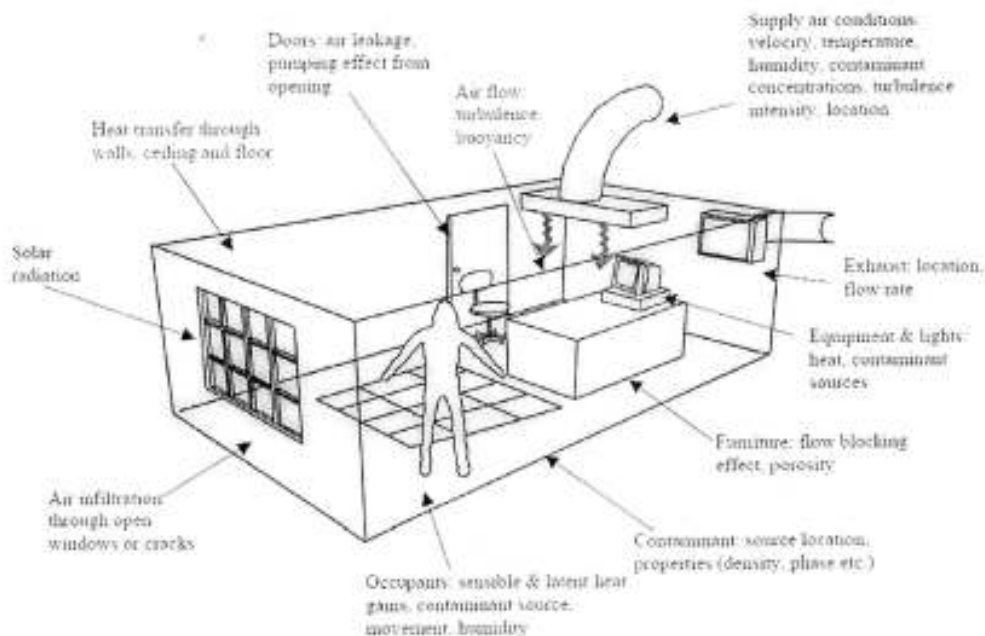


Figure 1 Schematic of the main factors influencing contaminant dispersion

4 Contaminant Dispersion Factors (Gant, et. al, 2006)

Summary about all the main factors affecting indoor contaminant dispersion that present on the schematic of Figure 1, divided into two main factors; primary and secondary factors. Primary factors that are clearly important in controlling the contaminant transport around the room include the contaminant properties and room ventilation. Secondary factors which perhaps may not seem initially so important include solar radiation, humidity and heat transfer through the walls, floor and ceiling.

Table 1 Summary of factors affecting contaminant dispersion.

Physical Room Feature	Factors Affecting Contaminant Dispersion
Doors	Door opening, pumping effect
Windows & walls	Thermal effects, radiation, infiltration
Occupants	Heat output, movement, breathing, flow blocking effects, spatial resolution
Equipment, lights & Furnishings	Heat output, flow blocking effects
Airflow	Turbulence, humidity, compressibility, supply terminals
Contaminants	Physical properties, electrostatic charge, source location, contaminant models

As usual, building have many physical room features. Every physical room feature can effect contaminant dispersion in that building/ rooms. The physical room feature consists of Doors; Windows and walls; Occupants; Equipment, light, and furnishing; Airflow; and Contaminants. The main factors that control the airborne transport of contaminants around the room are discussed.

Factors affecting contaminant dispersion in doors is size door opening and pumping effect. A study of the exchange of air from one room to another as a person walks through the doorway linking the two rooms entraining air in his/her wake was presented in Etheridge & Sandberg (1996). Also discuss the transient motion of air between rooms of different temperature when a door leading from one room to the other is opened. They present equations for the velocity and flow rate based on Bernoulli-type assumptions of frictionless flow. Keil & Watson (1989) measured the volume of air displaced either side of a door when it was opened and closed. Under isothermal and non-isothermal conditions using a 1:20 scale model, they found that for a 90° opening and shutting of the door there was a linear relationship between the pumped volume, V_p (measured in m³) and the mean door speed, u_d (in m/s measured at the door centre), given by:

$$V_p = 2.3u_d \quad (2)$$

where the pumped volume equates to around 50% of the volume swept by the door.

Factors affecting contaminant in Windows and walls are thermal effects, radiation, infiltration. For the thermal effects, the flow pattern in a room with displacement ventilation is primarily controlled by thermal sources. To model the contaminant dispersion behaviour in these rooms accurately, it is critical that heat transfer and buoyancy are accounted for appropriately. There is a significant amount of information on room heat loads in HVAC design guides such as CIBSE and ASHRAE, and building services engineering text books such as McQuiston & Parker (1994). The main heat sources or sinks in rooms include the following:

- Transmission of heat by conduction through solid surfaces: walls, ceiling and floors.
- Radiation between solid surfaces within the room
- Solar radiation through glazing
- Sensible and latent heat gains from occupants

- Heat gains from equipment, e.g. computers, lights
- Infiltration or air leakage

The three fundamental mechanisms of heat transfer are conduction, convection and radiation. *Conduction* involves the transmission of heat by collisions between molecules or atoms but does not involve any mass transfer. *Convection* involves a moving fluid (gas or liquid), and is often associated with heat transfer from a fluid to a solid or vice versa. *Radiation* is the transmission of energy by electromagnetic waves or photons. Unlike conduction and convection there does not have to be a carrier medium (gas/liquid/solid) in order to transmit radiation energy. And practically all structures leak air to some extent, allowing *infiltration* into or out of indoor spaces via small cracks around windows, walls and doors. This leakage can have considerable effect on heat loss calculations in cold climates.

Factors affecting contaminant dispersion by Occupants is heat output, movement, breathing, flow block effects and spatial resolution. The heat released by people is often tabulated in design guides in terms of sensible and latent heat loads [The two relevant chapters in ASHRAE Fundamentals are Chapter 8 - thermal Comfort and Chapter 29 - Nonresidential Cooling and Heating Load Calculation Procedures.] Sensible energy is related to the kinetic energy of the molecules and is proportional to the temperature of the fluid. Latent energy is related to the phase-change process between liquids and gases. For the movement, in real-life situations, the air flow pattern in rooms is unlikely to be statistically steady. Heat loads rarely stay constant over time. Over a day and throughout the year the outside air temperatures change, solar gains increase and decrease, occupants come and go and there are thermal inertia effects from the building fabric. A steady-state solution based on given outside temperature and solar radiation conditions may therefore differ from a snapshot of the transient calculation. Mattsson & Sandberg (1994) studied experimentally about how the moving manikin in a displacement ventilated room influence the contaminant concentrations at head height, were found to increase with the velocity of manikin, rising eventually to levels higher than the ambient conditions at the same height above the floor. And about breath, Goodfellow & Tähti (2001) explain that, the air flow through nasal passages is turbulent, even in normal quiet breathing, whilst flow further down in the pulmonary airways it is generally laminar. The human respiratory tract, including breathing mechanics, intra-airway airflow patterns, and heat and water vapour transport within the airways also influence contaminant dispersion. Although, there is little data on how to calibrate wall-roughness modifications of wall functions for application to indoor air flows, Nielsen (1998) discussed one example where furniture and other obstacles are modeled as an additional pressure drop in the momentum equations. Results were compared for scenarios with and without furniture, and he found the new term for support Momentum equation.

Next factor is equipment, lights and furnishing. The heat gains from lights are divided into two parts: a heat-to-space part which goes directly into the occupied zones, and a heat-to-return part which will be transferred into a ceiling void if there is a false ceiling in the room. For office equipment such as computers, printers and monitors, the nameplate data on the equipment itself does not give an accurate value for the actual heat output.

For airflow's contaminant dispersion is affected by turbulence, humidity, compressibility and supply terminal. Fluid flow can be classified into three regimes: laminar, transitional and turbulent. Laminar flow tends only to occur at low speed, with viscous fluids and in constricted spaces. The majority of flows relevant to contaminant dispersion are mixed laminar/turbulent or fully-turbulent. Computers are not yet sufficiently powerful to be able to directly resolve all of the fine eddy structures in industrial turbulent flows. Projections of future capabilities based on Moore's Law for the exponential growth of computing power have suggested that the so-called 'Direct Numerical Simulation' approach will only become a practical engineering tool in around 2070. In CFD simulations of indoor air flow, the phase-change of water from liquid to vapour due to people breathing and perspiring is not usually modelled. About humidity, can be an important factor controlling the release of other contaminants. Humidity can be an important factor

controlling the release of other contaminants. Nimmermark and Gustafsson (2005) studied a room used by laying hens and measured emissions of odor, ammonia, carbon dioxide and dust concentration. Both odour and ammonia emissions were found to increase significantly with water vapour pressure. High humidity inside buildings is also related to prevalence of mould allergens, fungi and bacteria. At low humidity there is a reduction in the electrical conductivity of clothing, carpets and soils, which may affect deposition of charged particulate contaminants. About compressibility, the ASHRAE Fundamentals guide states that compressibility effects, such as shock waves, are relevant when the Mach number exceeds 0.2. At room temperature and sea level, this equates to: $0.2 \times 343 = 69$ m/s. Air supply velocities in rooms are unlikely to ever exceed even 10 m/s (21 mph) and therefore compressibility effects are unlikely to have a significant impact on indoor air flow. There can be a wide range of length scales in indoor air flows, from an order of millimetres for heat-exchanger fins and diffuser blades up to spatial dimensions of tens or hundreds of metres for concert halls. Ideally, the computational mesh adopted in the CFD model should resolve all of these scales. However, due to limitations in computer power, the flow geometry is usually simplified and relatively low-resolution meshes are sometimes used. Then, data on typical supply terminal performance can be found in the report from ASHRAE's Research Project RP-1009. FLUENT used this information to develop its simple CFD code, *Airpak*, which is specifically aimed at the HVAC market. The code has performance data for a number of different types of terminals, including grilles, slots, nozzles, valves and vortex diffusers.

Want to know too about, physical properties, electrostatic charge, source location and contaminant models. The common contaminants in typical home or work environments (ASHRAE): Carbon Dioxide, Carbon Monoxide, Sulfur Oxide, Nitrous Oxides, Radon, Volatile Organic Compounds (VOC's), Particulate Matter. Due to the large range of possible contaminants, it is not possible to list all of their properties here. Instead, information can be found from the following references:

- ASHRAE Fundamentals, Chapter 12: Air Contaminants
- AirLiquide: gas data online
(<http://www.airliquide.com/en/business/products/gases/gasdata>)
- Thermodynamic tables
- Fluid dynamics textbooks and HVAC design guides
- Commercial CFD packages

Some contaminants are affected by changes in local flow conditions, for instance ammonia production in chicken litter is sensitive to local temperature and humidity. The UK Health Protection Agency recently investigated corona discharges from overhead power lines and their effect on electrostatically charging airborne pollutants. Results showed that for particles larger than about $0.3 \mu\text{m}$, the particle charge was unlikely to have a significant effect on deposition in the lungs, but for smaller particles, around $0.1 \mu\text{m}$ in diameter, there was up to a three-fold increase in deposition. The HPA work concluded that contaminant particles charged electrostatically from power lines were unlikely to have more than a small effect on long-term health. There is a considerable amount of material available in the literature regarding electrostatic air filters (precipitators or charged-media filters) and room air ionizers. The latter devices work by electrostatically charging particles suspended in room air which are then attracted to walls, floors, table tops, occupants, etc. The location of contaminant sources can have a significant effect on occupational exposure. Results of (Etheridge & Sandberg (1996)) showed that contaminants released below the stratification layer, either near the floor or low down on a wall, tended to accumulate below the stratification layer and were gradually convected horizontally towards heat sources. A number of different techniques are used to model contaminant transport in CFD. The choice of technique depends on the characteristics of the contaminant: whether it is gaseous or particulate, its density relative to air, its concentration, the required accuracy of the simulation and the computing time that can be afforded. For particulate

contaminants, one of the central questions is whether the particles can be modeled as a fluid continuum with defined diffusivities (the Eulerian approach), or whether particle-tracking should be adopted (the Lagrangian approach). It is beyond the scope of the current report to investigate fully the range of modeling practices for multi-phase flows. A separate research proposal on this subject is currently being evaluated, i.e. Schmidt Numbers as in <http://www.advantica.biz/gasvle>.

5 Respiratory System

It is important to prepare in this paper about points of practitioner's guide to managing indoor air quality ([9], accessed February 2007) and regulation of breathing ([28], accessed February 2007) to show positioning of this kind of respiratory system research study. **Table 2** show the highlight conditions related to each category of symptom complex illness health effect about contaminant. They are certainly not medically definitive. To be accurate as possible, the terms used by the epidemiologist and other reporting their research were used verbatim; e.g., "dry cough" and "coughing," and no medical interpretations were attempted. Rather, the table are designed to help the practitioner sort through what is known, the symptoms, and to discern possible contaminants/sources.

Table 2 The Practitioner's Guide to Health Effects, Contaminants and Environmental Factors (Managing Indoor Air Quality, p66)

<i>Symptom Illness</i>	<i>Complex Health Effect</i>	<i>Possible Contaminants</i>	<i>Primary Sources</i>	<i>Environmental Conditions</i>
Eye Irritation:	burning, dry gritty eye without inflammation	NO2 Formadehyde	Incomplete Combustion-- stoves, fireplaces, ETS Building products & furnishing	Artificial light Low relative humidity
Water eyes		VOCs (Volatile Compounds) Bioaerosols	Broad range of products Ventilation systems, humidifiers, dehumidifiers wet insulation, drip pans, cooling coils in Air Handling Units (AHUs), peoples pets, plants, insects, outside air	
		Particulates	Combustion products, ETS, dust, dirt, maintenance products, building products deterioration, outside air	
Nasal manifestations:	"Stuffiness"	NO2	Incomplete combustion— stoves, fireplaces, Environmental Tobacco Smoke (ETS) heaters	Artificial light
Nasal Irritations, rhinorthoea		Formaldehyde	Building products & furnishings	Low relative

Bioaerosols	Ventilation systems, humidity humidifiers, dehumidifiers wet insulation, drip pans, cooling coils in AHUs, peoples pets, plants, insects, outside air
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Step by step Gas Exchange and Transport in our Respiratory system are (28):

1. Chemical Analysis of the gases that are inhaled and exhaled:

GAS INHALED	-vs-	EXHALED
O ₂ 20.71%		14.6%
CO ₂ 0.04%		4.0%
H ₂ O 1.25%		5.9%

2. Three Important things happen to the air we inhale: A. Oxygen is removed, B. Carbon Dioxide is added, C. Water vapour is added.

3. This occurs in the ALVEOLI in the LUNGS; Our Lungs consist of nearly 300 million ALVEOLI where gas exchange occurs (The exchange of Carbon dioxide and Oxygen).

4. Blood flowing from the HEART enters Capillaries surrounding each Alveolus and spreads around the Alveolus. This Blood contains a LARGE AMOUNT of CO₂ and Very Little O₂.

5. The Concentration of the gases in the blood and the alveolus are not Equal (Concentration Gradient). This causes the DIFFUSION of CO₂ from the Blood to the Alveolus and the DIFFUSION of O₂ from the Alveolus into the Blood.

6. The Blood leaving the alveolus has nearly tripled the total amount of oxygen it originally A. MACROMOLECULES - Soaplike, consisting of phospholipid and protein, they coat the inner surface of the Alveolus. B. HEMOGLOBIN - An Oxygen Carrying Molecule that is a component of Blood. Hemoglobin is a red colored protein found in red blood cells. Each Hemoglobin molecule has FOUR SITES to which O₂ atoms can bind. Thus, One Hemoglobin molecule can carry up to Four molecules of oxygen. Most of the oxygen - 97 percent - moves into the red blood cells, where it combines with Hemoglobin.

6 Characteristics of Indoor Air Flows

Gant, et. al, (2006) state a number of parameters which can be used to characterize the dispersion of contaminant inside a room, i. e.:

1. Fresh Air/ Contaminant Distribution:

Contaminant Concentration, Local Mean Age of Air, Purging Effectiveness of Inlets, Local Specific Contaminant-Accumulating Index, Air Change Efficiency, Ventilation Effectiveness Factor, Relative Ventilation Efficiency.

2. Stability and Bouyancy of the Room Air:

Reynold Number, Rayleigh Number, Grashof Number, Froude Number, Richardson Number, Flux Richardson Number, Bouyancy Flux.

3. Temperature Distribution:

Air Diffusion Performance Index, Effective Draft Temperature.

4. Supply Air Conditions:

Purging Effectiveness of Inlet, Reynold Number, Froude Number, Archimedes Number.

Due to overlap between these subjects, some parameters appear more than once. Some parameters characterize directly the observed pattern of contaminant distribution, whilst others characterize flow features, such as stability. Flow parameters such as the 'mean age of air' are difficult but not impossible to calculate experimentally. They are used mainly as a tool to help interpret data from numerical simulations of contaminant dispersion. For discussions on how these parameters are used to assess compliance with standards on room air quality, see Peng & Davidson (1999) or the ASHRAE Guides (2003).

Clearly the simplest indicator of contaminant distribution in a room is the **contaminant concentration**, i.e. the mass of contaminant per unit volume of air (measured in kg/m^3). Contaminant concentration is sometimes expressed in terms of parts per million (ppm), or parts per billion, trillion etc. This can be based on either the mass fraction or the volume fraction.

Local Mean Age of Air is commonly used to evaluate the performance of a ventilation system and indoor air quality. The precise meaning of the local mean age is defined in Di Tommaso *et al.*; (1999) as follows: "the average time it takes for air to travel from the inlet to any point P in the room".

The purging effectiveness of an inlet is a quantity that can be used to identify the relative performance of each inlet in a room where there are multiple inlets.

Peng *et al.*; (1999) classify the various measures used to characterize ventilation performance into three groups: measures of *ventilation air-diffusing efficiency* which indicate the ability to provide fresh air to occupants, *ventilation effectiveness* which indicate the ability to remove contaminants from a ventilated space and *specific ventilation effectiveness* which deals with specific situations.

Air Change Efficiency is a measure of how effectively the air present in a room is replaced by fresh air from the ventilation system (Di Tommaso *et al.*; 1999). It is the ratio of the room mean age that would exist if the air in the room were completely mixed to the average time of replacement of the room.

The Ventilation Effectiveness Fraction (VEF) appears to be ASHRAE's preferred method for characterizing indoor air quality and is based on the work of Zhang *et al.* (2001).

The relative ventilation efficiency is the ratio of the local mean age that would exist if the air in the room were completely mixed to the local mean age that is actually measured at a point.

Air Diffusion Performance Index (ADPI) is primarily a measure of occupant comfort rather than an indicator of contaminant concentrations. It expresses the percentage of locations in an occupied zone that meet air movement and temperature specifications for comfort.

The temperature effectiveness is similar in concept to ventilation effectiveness and reflects the ability of a ventilation system to remove heat.

The effective draft temperature, θ , indicates the feeling of coolness due to air motion:

$$\theta = (T_s - T_r) - 8(V_s - 0.15) \quad (3)$$

where T_s and T_r are the local air-stream and average room dry-bulb temperatures (in °C or K), V_s is the local air-stream centre-line velocity (in m/s) and θ is measured in K.

The Reynolds number, Re , expresses the ratio of the inertial forces to viscous forces:

$$Re = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{UL}{\nu} \quad (4)$$

where U and L are characteristic velocity and length scales of the flow and ν is the kinematic viscosity.

Natural convection flows are often characterized using the Rayleigh Number, Ra , given by:

$$Ra = \frac{g\beta\Delta TL^3}{\nu\alpha} \quad (5)$$

where g is the acceleration due to gravity ($g = 9.81 \text{ m/s}^2$), β the coefficient of thermal expansion (where for an ideal gas, $\beta = 1/T$), ΔT the temperature difference, L the length scale (e.g. the height of the heated surface), ν the kinematic viscosity and α the thermal diffusivity ($\alpha = k/\rho C_p$).

The Grashof number, Gr , is equivalent to the Rayleigh number divided by the Prandtl number:

$$Gr = \frac{Ra}{Pr} = \frac{g\beta\Delta TL^3}{\nu^2} \quad (6)$$

where g is the acceleration due to gravity, β the coefficient of thermal expansion ΔT temperature difference, L the length scale and ν the kinematic viscosity.

The following form of the Froude number is used by Linden [6] to characterize flow through corridors and doorways and in combined displacement and wind ventilation cases.

$$Fr = \frac{U^2}{gL} \quad (7)$$

where U and L are characteristic velocity and length scales, respectively, and g the acceleration due to gravity.

The Richardson number, Ri , characterizes the importance of buoyancy. It is calculated from:

$$Ri = \frac{gL\Delta\rho}{U^2\rho} \quad (8)$$

where $\Delta\rho$ is the density difference that occurs over a typical (usually vertical) length scale, L , in a flow of velocity, U .

The flux Richardson number, Ri_f , is used to characterize the stabilizing effect of stratification on turbulence:

$$Ri_f = -\frac{P_b}{P_s} \quad (9)$$

where P_b and P_s are the turbulence production due to buoyancy and shear respectively

The buoyancy flux, B , is calculated from:

$$B = \frac{g\beta W}{\rho c_p} \quad (10)$$

Linden (1999) uses this to characterize buoyancy driven flows, where W is the heat flux, $\beta = 1/T$ is the coefficient of expansion and c_p is the specific heat capacity at constant pressure.

The conditions of the supplied air are often characterized by the discharge Archimedes number, Ar , which expresses the ratio of the buoyancy forces to momentum forces or the strength of natural convection to forced convection:

$$Ar = \frac{g\sqrt{A} \Delta T}{U^2 L} \quad (11)$$

where $T \Delta$ is the temperature difference between supply and exhaust, U is the initial velocity of the discharged air, g is the acceleration due to gravity and L is the length scale of the supply terminal (i.e. diffuser or grille).

7 Aerosol Particles: an overview

What is an AEROSOL? From ([28]-[35, Hinds., 1999), simply defined- tiny particles or droplets suspended in air. An aerosol is defined as a suspension of solid or liquid particles in a gas (Seinfeld and Pandis, 1998; <http://cloudbase.phy.umist.ac.uk/people/dorsey/Aero.htm>). Since 1970's, aerosol particles have been distinguished as fine and coarse (Whitby, 1978). Coarse refers to the portion of PM larger than 2.5 micro-meter in diameter, and fine refers to the portion of PM smaller than 2.5 micro-meter in diameter. Aerosol particles smaller than 1.0 micro-meter are known as submicron particles. The fine aerosol particles, or more specifically submicron aerosol particles, are composed of nucleation modes, Aitken mode, and accumulation mode (**Figure 2**). However, Nazaroff (2004) classified particles according to their diameter into three size modes: ultrafine (0.1 micron), accumulation (0.1–2 micron), and coarse (2 micron).

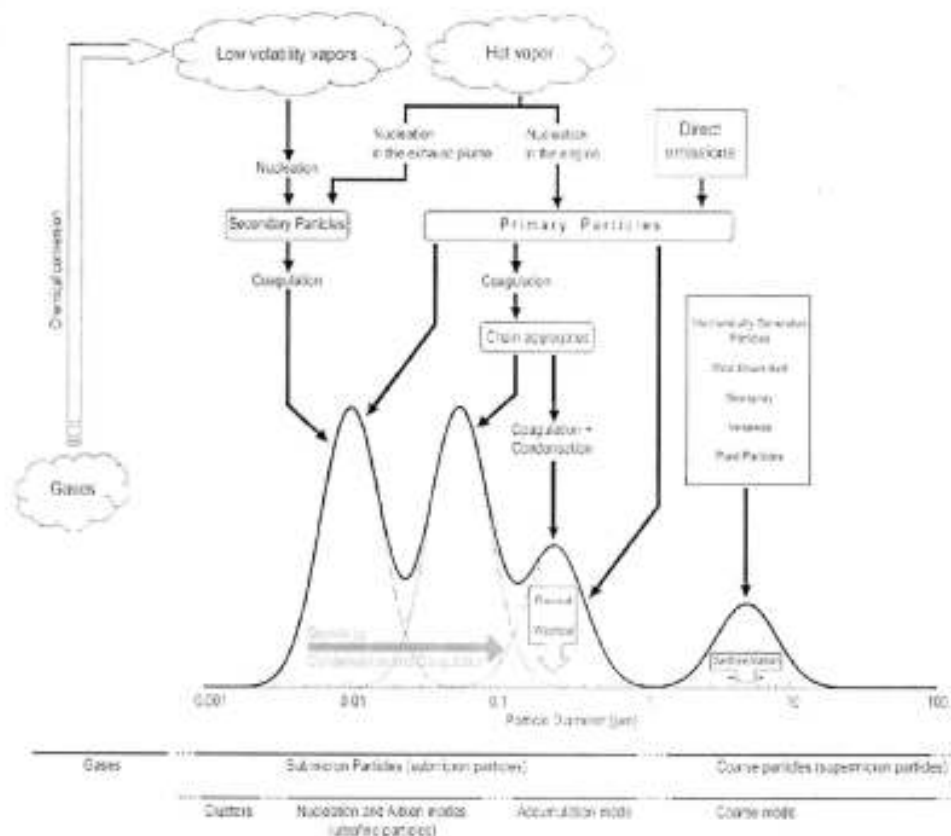


Figure 2 Idealized schematic of an atmospheric particle number size distribution. Principle modes, sources, and particle formation and removal mechanisms are indicated after (Hussein, T., 2005).

8 Impact of Air Quality (<http://www.cleanairenet.org/baq2006/1757/propertyvalue-26750.html>)

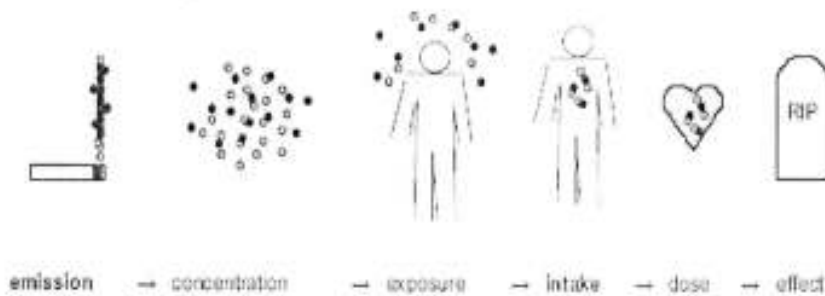


Figure 3 Source-oriented, air pollution health effects paradigm. After Smith (1993,2001) Nazaroff, 2006).

Control measures (for example: improve airflow) are often best targeted at sources and their emissions. The control of contaminants indoors is achieved by one of the following methods: source control, dilution control, or removal control. Although source control is preferred, this option is not always available. Thus, ventilation and air filtration are the main remedial actions applied to reduce exposure to airborne contaminants indoors.

From <http://www.pciaonline.org/references.cfm> and <http://www.arecop.org/> we have information about impact of air pollution on the health, environment and economy. The impacts have been fairly studied by various institutions and for different periods. Despite the difference in methodologies, all the studies agree that the cost of air pollution are very substantial and that morbidity and mortality costs are expected to increase if the air pollution remains unabated.

Table 3 Economic Value for Each Air Pollution Related Health Case [Better Air Quality Forum, Yogyakarta (2006)]

Pollutant	Health Effect	Estimates for 2001 in rupiah
PM10	Premature mortality (million)	92
	Restricted activity day	17,050
	Hospital admission	823,050
	Emergency room visits	135,170
	Asthma attacks	24,650
	Lower respiratory illness a/g children	11,900
NO2	Respiratory symptoms	11,900
SO2	Chronic Bronchitis	57,266
	Respiratory Symptoms	11,900
	Premature Mortality	92,157,163
	Lower Respiratory Illness a/g Children	11,900
	Chest Discomfort a/g adult	11,900

9 Review of the Airflow and Aerosol Dynamics

There are many Models that use to modelled the air flow and the pollutant transport in the building. For example: COMIS (Feustel, 1993), CONTAM (Walton,1997) that have the same mathematical formulations. The first link between COMIS-multizone air flow and the pollutant dynamics indoor especially in chamber from Environment Tobacco Smoke had been success (Michael, et. al, 2006).

9.1 COMIS (Feustel, 1999)

Conjunction Of Multizone Infiltration Specialists (COMIS) was developed in 1988-89 by ten scientists from nine countries, during a twelve-month workshop hosted by the Lawrence Berkeley National Laboratory (LBNL). Belgium, Canada, France, Greece, Italy, Japan, Switzerland, The Netherlands, and USA. COMIS is multi-zones airflow model or multi-compartment air flow

model (Feustel, 1999). The air flow pattern in a building influences indoor air quality and thermal space conditioning loads. Correct sizing of HVAC (heating, ventilation and air-conditioning) systems should also be based on indoor air flow considerations. Air flows and their distribution in a given building are caused by pressure differences that can be induced by wind, thermal buoyancy, mechanical ventilation, or a combination of these factors. Building-related properties such as the distribution of openings in the building shell, inner pathways, and occupant activity can also create indoor pressure differences. Two methods exist for characterizing indoor air flow rates: performing air flow measurements using tracer gas techniques, and using mathematical models to model the indoor air flows.

Measurements based on tracer gas techniques can determine the air flows between the inside and the outside of the building, as well as interzonal air flows. However, because tracer gas measurements reflect the prevailing leakage and weather conditions at measurement time, their use in characterizing general building leakage is limited. To describe indoor air flows for any leakage and weather conditions, a number of mathematical models describing interzonal air flow have been developed. One advantage to using these mathematical models is that, in addition to air flows, they can also simulate indoor contaminant transport.

COMIS is one of the most recently developed air flow models. It can be used as a stand-alone program with input and output features, or as an infiltration module that can be integrated into thermal building simulation programs. COMIS is a FORTRAN-based code. COMIS models the air flow and contaminant distributions in buildings. The program can simulate several key components influencing air flow: cracks, ducts, duct fittings, fans, flow controllers, vertical large openings (windows and/or doors), kitchen hoods, passive stacks, and "user-defined components". COMIS allows the user to define schedules describing changes in the indoor temperature distribution, fan operation, pollutant concentration in the zones, pollutant sources and sinks, opening of windows and doors, and the weather data. The flexible time step implemented in COMIS enables the modeling of events independent of the frequency with which the weather data are provided. The COMIS air flow calculation is based on the assumption that indoor air flows reach steady-state at each time step. The contaminant transport is based on a dynamic model and has its own time step, based on the time constant of the most critical zone. The two models are coupled. Results for air flows and contaminant levels are reported in terms of tables by COMIS and in graphical form by some of the user-interfaces.

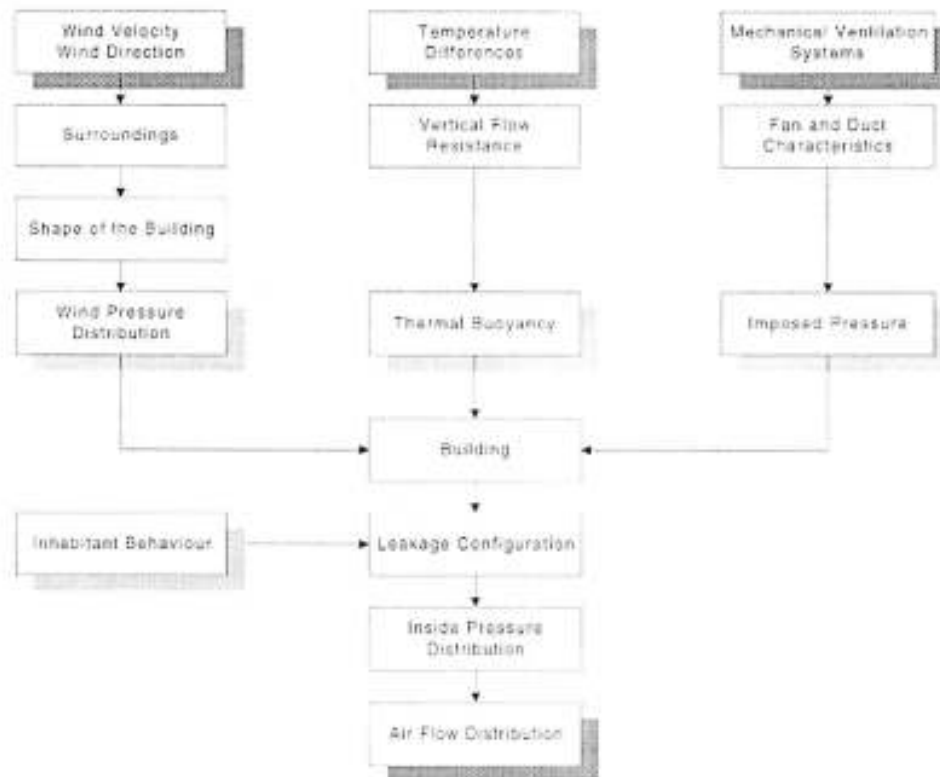


Figure 4 Influences on the air-flow & distribution in a given buildings

The wind produces a velocity and pressure field around a building. The relationship between velocity and the pressures at different locations in the flow field can be obtained by analyzing the dynamics of a particle in fluid. The pressure distribution around a building is usually described by dimensionless pressure coefficients:

$$c_p(x, y, z) = \frac{p(x, y, z) - p_o(z)}{p_{dyn}(z)}$$

$$p_{dyn}(z) = \frac{1}{2} \rho_{out}(z) v^2(z)$$

- $c_p(x, y, z)$ = pressure coefficient at coordinates x, y, z [-];
- $p(x, y, z)$ = surface pressure at coordinates x, y, z [Pa];
- $p_o(z)$ = atmospheric pressure at height z [Pa];
- $p_{dyn}(z)$ = dynamic pressure in the undisturbed flow at height z [Pa];
- $\rho_{out}(z)$ = density of outside air at height z [kg/m³], and
- $v^2(z)$ = wind speed at height z [m/s].

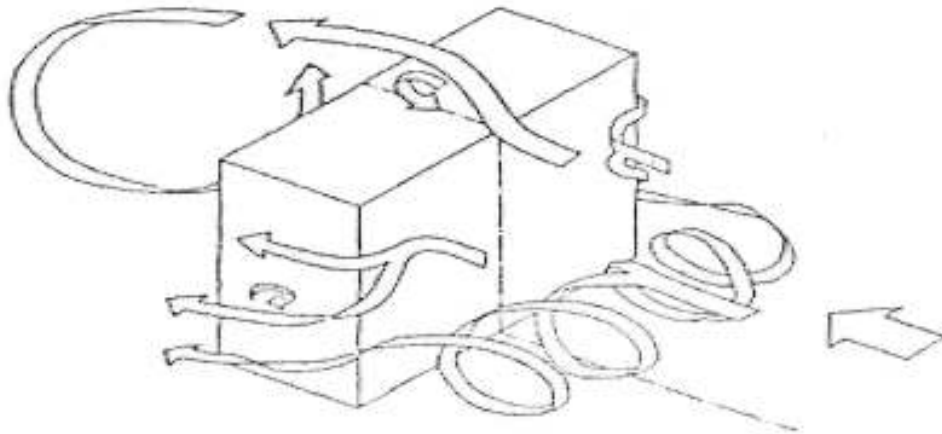


Figure 4 Air flow around an isolated building.

A wind velocity profile can be approximated either by a logarithmic equation or a power law as:

$$V(z) = V(z_0) \left[\frac{z}{z_0} \right]^a \quad (12)$$

where: $v(z)$ =wind speed at height z [m/s]; $v(z_0)$ =wind speed at reference height z_0 [m/s], and a =exponent.

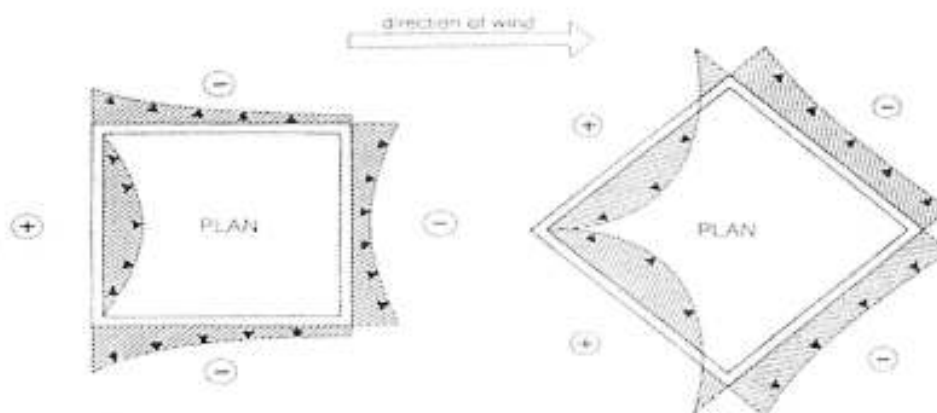


Figure 5 Simplified wind pressure distribution; (a) wind direction perpendicular to surface. (b) wind direction 45 degrees.

The stack effect (or thermal buoyancy) can be calculated by integrating Bernoulli's equation, assuming no wind:

$$(\rho_{out}-\rho_{in})_{stack}=g(\rho_{in}-\rho_{out})(z-npl) \quad (13)$$

where: $(\rho_{out}-\rho_{in})_{stack}$ =pressure difference due to stack effect [Pa]; g =constant of gravity [m/s²]; $(\rho_{in}-\rho_{out})$ =density difference between outside and inside air column [kg/m³], and $(z-npl)$ =distance between height z and neutral pressure level [m]. Temperature differences between inside and outside air create air density differences that cause pressure gradients.

9.2 MIAQ4 (Nazaroff and Cass, 1989)

MIAQ4 stated for the Multi-chamber Indoor Air Quality, Model Formulation, start from Aerosol Representation; Basic Model Postulates; Ventilation and Filtration; Aerosol Deposition onto Surfaces; Coagulation; Other Elements; Outdoor Concentrations, Initial Conditions, Indoor Emissions; Computer Implementation Notes. Test of Performance of MIAQ4; Evolution of Cigarette Smoke.

Aerosol Representation:

- The multi-component sectional formulation of Gelbard and Seinfeld (1980) is used to represent the indoor aerosol.
- The complete aerosol size distribution is divided into number of contiguous section or bins, and within each section the aerosol mass may be comprised of many different chemical components.

Following Warrant and Seinfeld (1985), the mass concentration within a section is assumed to be uniformly distributed with respect to the Particles are assumed to be spherical and to have equal densities so that a particle's mass is uniquely related to its diameter, and either may be used as basis for specifying the size distribution.

Components are assumed to be mixed internally, i.e., within a section all particles have the same composition.

A geometric constraint is imposed on the width of a section: **the largest particle in each section must have a mass that is at least twice that of the smallest particle in the section** so that, to limit the computational simulation coagulation logarithm of the mass (or, equivalently, the diameter) of the particle.

Basic Model Postulates:

- by using the same approach for modeling gaseous pollutants in building. Rate of change of aerosol mass concentration for each component within each section is given by FOD-equation:

$$dC_{jk} / dt = S_{jk} - L_{jk} C_{jk} \quad (14)$$

C_{jk} =the mass concentration of component k in section j contained within chamber i ;

- S_{ijk} =the sum of all sources within chamber i of component k in section j : direct emission, advective transport from other chamber and outside, and coagulation of mass from smaller particles into the section.
- L_{ijk} =the sum of all sinks within chamber i of component k in section j : loss to surfaces, removal by ventilation and filtration, and loss to a larger size due to coagulation.
- Note: The source and sink terms may, of course, vary with time.

The effect of Ventilation and Filtration on aerosol species:

$$\frac{dC_{ijk}}{dt} = \left[\sum_{h=0}^n \left(\frac{f_{hi} C_{hjk} - f_{ih} C_{ijk}}{V_i} \right) \right] + \left(\frac{f_{x0} C_{xjk} - f_{0x} C_{ijk}}{V_i} \right) - \frac{\eta_{ij} f_{ij} C_{ijk}}{V_i} \quad (15)$$

$$C_{ijk} = \frac{\sum_{h=0}^n (1 - \eta_{ih}) f_{hs} C_{hjk}}{\sum_{h=0}^n f_{hs}} \quad (16)$$

- V_i =the volume of chamber i ;
- f_{ih} =the volumetric flow rate of air from chamber i to chamber h ;
- η_{ij} =the efficiency of removal of aerosol section j by the filter located in the air stream flowing from chamber i to chamber h ;
- x =mechanical ventilation system supply air, and
- $h=0$ is reserved to denote outdoor air.
- Ventilation through doors thus represent fluxes between chamber 0 and chambers 1 through n .

Aerosol deposition onto surfaces:

$$\frac{dC_{ijk}}{dt} = -\frac{C_{ijk}}{V_i} \sum_m v_{dim} A_m \quad (17)$$

- v_{dim} =the mean deposition velocity of particles in section j to the m th surface chamber i ,
- A_m =the superficial area of the m th surface of chamber i .

Coagulation:

The treatment of aerosol coagulation in the model is best considered in two stages: the calculation of the collision frequency between two particles and the integration of these probabilities to obtain the growth and loss rates for component masses within each section.

Inputs of MIAQ4

(1)airflow between rooms (predicted by COMIS); (2)an emission rate profile for sidestream ETS particle (as in Nazaroff and Cass, 1989; Miller and Nazaroff, 2001)—[emissionrate = f (dia.particle)]; (3)chamber dimension; (4)intermittent use of filter pumps; (5)the turbulence

intensity factor for the chamber (describe the stream wise velocity gradient at the vicinity of the chamber wall)

Outputs of MIAQ4

(1)ventilation air flow in chamber; (2)ETS particles mass from smoking; (3)Predicted concentration of ETS; (4)Predicted concentration of ETS in every room.

9.3 -COMIS-link-MIAQ4- (Michael D. Sohn, et al., 2006)

This is the first linked COMIS and MIAQ4 for Aerosol resolved particle indoor (Michael D. Sohn, Michael G. Apte, Richard G. Sextro, Alvin C. K. Lai, 2006.). Link between COMIS and MIAQ4 is Perl scripts.

Input of COMIS:

- (1)sigma rooms,
- (2)dimension of rooms (building),
- (3)size of door openings,
- (4)room temperature as function of time,
- (5)leakage between the chamber & the outside

Output of COMIS=Input MIAQ4:

- Current airflows between rooms (mainly needed of MIAQ4)
- Air flows for each time step
- Pollutant transport data for each time step
- Include:
 - Air change rates for individual zones and / or the whole building.
 - Mean age of air,
 - The air change efficiency of the building, and
 - The room air change index.
- Possible:
 - Mean value for the whole simulation period being calculated and reported.
 - The ventilation heat loss energy, based on incoming air temperature and the temperature difference between inside and outside of building.

9.4 MC-SIAM (Hussein, et. Al, 2005.)

MC-SIAM (Multi Compartment Size-resolved Indoor Aerosol Model) classified to indoor aerosol model because Hussein, et. al, (2005) assume that the aerosol particle number size distribution in each compartment is affected by several processes that typically depend on the particle size (Process penetration of aerosol particles across the building shell and via the ventilation system, Deposition and re-suspension of aerosol particles indoors, Evolution of particle size distribution within each compartment is based on a modified and extended dynamic scheme of aerosol model UHMA (University of Helsinki Multicomponent Aerosol).

9.5 CONTAM (Dols, W.S., Walton, G.N, 2002)

CONTAM stated for Contaminant monitoring (Dols, W.S., Walton, G.N, 2002). Keywords of this program are airflow analysis; building controls; contaminant dispersal; indoor air quality, multizone analysis, smoke control, smoke management, ventilation. Figure 5 is an example's feature todays version of CONTAM, 2.4b.

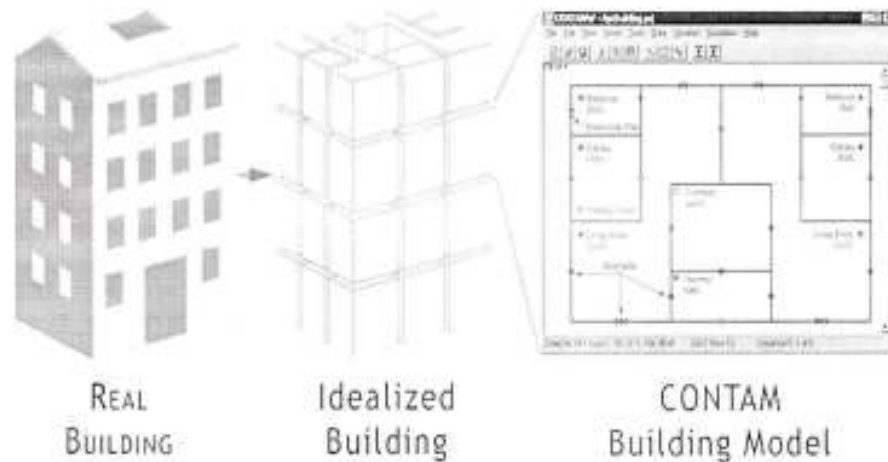


Figure 5 Welcome to the NIST Multizone Modeling website (<http://www.bfrt.nist.gov/LAQanalysis/>)

9.6 CFD

CFD (Computational fluid dynamics) is not the only technique that can be used to simulate contaminant transport in rooms. Etheridge & Sandberg (1996) present a number of simplified analytical models which calculate contaminant concentrations based on the source location, mass transfer coefficient, geometry of source, velocity of emission and time history. The advantage of CFD over these alternative treatments is its generality: it can provide reasonably accurate results for a range of different flows and relies less upon case-specific empiricism. That is not to say that CFD always gives good results. It should be noted that whilst CFD offers advantages in terms of accuracy and generality, it can also be significantly more expensive than the simple modelling approaches in terms of computing time.

9.6.1 Turbulence Model for Contaminants Dispersion (Grat, et. al, 2006)

Grat, et. al, (2006) provide guidance on the accuracy of different turbulence models and to give practical advice on how best to simulate a contaminant dispersion problem. To assess the dispersion of a contaminant over large distances and over long physical time periods (many hours or days) simple models may be the only practical approach available. The discussion in this report has been limited to consideration of the physical models. For information on numerical methods, including differencing schemes and convergence criteria, see for example Sorensen & Nielsen (2003) and Khamel and Khalil, (2003).

9.6.2 Turbulence Models (Khamel and Khalil, 2003)

Three models, namely Turbulence standard k-ε model (Launder and Spalding), Turbulence ReNormalization Group (RNG) model and the Turbulence Phenomenological model of (Li and Zhao)

that based on DNS (Directly Numerical Simulation) data have been used to prediction airflow regimes in surgical operating theatres (Khamel and Khalil, 2003). Because proper predictions of airflow regimes inside the healthcare applications, especially the surgical operating theatre, enhance our design decisions of the HVAC systems or even the earlier architecture design. Also, proper turbulence models can aid in that task, which lead engineers to accurate description of the airflow characteristics inside the surgical operating theatres. The obtained results suggest the use of the approximate model for engineering purpose. The k-ε model is superior in predicting flow characteristics in near wall and steep gradient zones.

8 Conclusion and Discussion

More than four models simulation airflow for building that must be have at least one room or zone is reviewed. Further study about details guidance have been established in Gant, et. al (2006) for many type of contaminant to present the current study about contaminant dispersion and control by CFD, in Khalil and Khamel (2003) to prediction airflow regime in healthcare application.

This report has described the main factors affecting contaminant dispersion in rooms. Information has been provided on how to quantify the relative importance of different factors and how to characterize the distribution of contaminants in rooms. Guidance has also been given on the inclusion of these factors in at least in CFD models especially from Gant (2006), Khalil and Khameel (2003), Sorensen & Nielsen (2003).

So, Indoor Air Quality (I.A.Q.) is no longer just maintaining comfort, it is now a must in any home. Today's I.A.Q. problems including electronic air cleaners, a variety of filters and filter media, and dehumidification. Air quality is as important as air temperature. So, we can used one of many software, however still in development. We only need to study it more then by well-considered.

It's a good effort that Indonesia is one of more than 11th countries that give a better commitment to Better Air Quality (BAQ) in Asia regional. (<http://www.cleansairmet.org/baq2003/1496/propertyvalue-18343.html>)

9 Example Consideration step by step Manage Contaminant in Building (Green Building Rating System Version 2, 2000)

To make effort and achieve in high quality of Indoor Environment, Green Building Rating System Version 2, (2000) suggests to start with existing user amenities, such as dining, recreation, socialization, shopping and child care facilities. First step is to identify what amenities should be incorporated into the project or provided in a future, nearby facility. Provide environmental noise control through the appropriate use of insulation, sound-absorbing materials and noise source. Provide ventilation air in sufficient volume free from natural and man made contaminants. Limit humidity to a range that minimizes mold growth and promotes respiratory health. In Green Building Rating System, user give a list of tool serves as a roadmap throughout the design process to become higher Indoor Environmental Quality (IEQ). **IEQ Prerequisite 1: Minimum IAQ Performance.** INTENT: Establish minimum IAQ performance to prevent the development of indoor air quality problems in buildings, maintaining the health and well being of the occupants. REQUIREMENT: Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality and approved Addenda. TECHNOLOGIES/STRATEGIES: Include proactive design details that will eliminate some of the common causes of indoor air quality problems in buildings. Introduce standards into the design process early. Incorporate references to targets in plans and specifications. Ensure ventilation system outdoor air capacity can meet standards in all modes of operation. Locate building outdoor air intakes away from loading areas, building exhaust fans, cooling towers, and other sources of contamination. Include operational testing in the building commissioning report. Design cooling coil drain pans to ensure complete draining.

IEQ Prerequisite 1, followed by 2, 3, etc, then IEQ Credit. **IEQ Credit 1: Carbon Dioxide (CO₂) Monitoring.** INTENT: Provide capacity for indoor air quality (IAQ) monitoring to sustain long term

occupant health and comfort. **REQUIREMENT:** Install a permanent carbon dioxide (CO₂) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments, **AND** specify initial operational set point parameters that maintain indoor carbon dioxide levels no higher than outdoor levels by more than 530 parts per million at any time. **TECHNOLOGIES/STRATEGIES:** Install an independent system or make CO₂ monitoring a function of the building automation system. Situate monitoring locations in areas of the building with high occupant densities and at the ends of the longest runs of the distribution ductwork. Specify that system operation manuals require calibration of all of the sensors per manufacturer recommendations but not less than one year. Include sensor and system operational testing and initial set point adjustment in the commissioning plan and report.

IEQ Credit 2: Increase Ventilation Effectiveness

IEQ Credit 3: Construction IAQ Management Plan

IEQ Credit 4: Low-Emitting Materials

IEQ Credit 5: Indoor Chemical and Pollutant Source Control

IEQ Credit 6: Controllability of Systems

IEQ Credit 7: Thermal Comfort

IEQ Credit 8: Daylight and Views

In detail of every Intent, Requirement and Technology/Strategy we can see Green Building also.

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