Numerical Analysis of Contaminants Control in the Air-Conditioned Hospitals Wards

By

Eng. Mona Ahmed Abdel-Mawla

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfilment of the
Requirements for the Degree of
Master of Sciences

In
MECHANICAL POWER ENGINEERING

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Under Supervision of

Prof. Dr. Mahmoud A. Fouad

Professor, Mechanical Power Engineering
Department Faculty of
Engineering, Cairo University

Prof. Dr. Essam E. Khalil

Professor, Mechanical Power Engineering
Department Faculty of
Engineering, Cairo University

Dr. Kareem Awny

Lecturer, Mechanical Power Engineering
Department Faculty of
Engineering, Cairo University

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Prof. Dr. Mahmoud A. Fouad Professor, Mechanical Power Engineering, Faculty of Engineering, Cairo University	**Thesis main Advisor**
Prof. Dr. Essam E. Khalil Hassan Khalil Professor, Mechanical Power Engineering, Faculty of Engineering, Cairo University	**Thesis Advisor**
Prof. Dr. Samy Morad Morcos Professor, Mechanical Power Engineering, Faculty of Engineering, Cairo University	**Internal Examiner**
Prof. Dr. Mohamed Fayek Abd Rabbo Professor, Mechanical Power Engineering, Shobra Faculty of Engineering, Benha University	**External Examiner**

Faculty of Engineering, Cairo University

Giza, EGYPT

2017

Engineer: Mona Ahmed Abdel-Mawla
Date of Birth: 24 / 11 / 1990
Nationality: Egyptian
E-mail: monaahmed2411@gmail.com@yahoo.com
Registration Date: 1 / 10 / 2013
Awarding Date: / /
Degree: Master of Science
Department: Mechanical Power Engineering Department

Supervisors: Prof. Dr. Mahmoud A. Fouad
Prof. Dr. Essam E. Khalil
Dr. Kareem Awny

Examiners: Prof. Dr. Mahmoud A. Fouad
Prof. Dr. Essam E. Khalil
Prof. Dr. Samy Morad Morcos
Prof. Dr. Mohamed Fayek Abd Raboh (Professor- Faculty of Engineering - Banha University)

Title of Thesis: **Numerical Analysis of Contaminants Control in the Air-Conditioned Hospitals Wards**

Key Words: **(Air-conditioned Hospitals, Contaminants, Ward room, CFD)**

Summary:

The aim of this study is to make numerical analysis of indoor air quality and comfort factors in the wardrooms of the air-conditioned hospital, taking into account the ways to improve these factors, whether by studying many of the proposed designs for air conditioning systems or by studying the source of contaminant emissions and studying how to reduce the emission rates in respiratory areas. This thesis suggested that the carbon dioxide CO_2 produced by respiration is an indicator of the spread of infectious emissions from patients within the ward.

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NOMENECLATURE

Symbol	Description
A	Body surface area, m^2
$\vec{A}_j$	The j face area vector, m^2
C_c	The Cunningham correction factor
C_n	The maximum permitted number of particles per cubic meter.
c_p	Specific heat of fluid, kJ/kgK
$D_{i,m}$	The diffusion coefficient for speciesi, m^2/s
d_p	Particle diameter, m
F_a	Additional forces (per unit mass), N/kg
F_b	Brownian force, N
F_{drag}	Drag force, N
Fs	Lift force, N
F_{therm}	Thermophoretic force, N
G_b	The generation of turbulence kinetic energy due to buoyancy, kg/m s^3
G_i	The component of the gravitational vector in the ith direction, m/ s^2
$\vec{J}_i$	The diffusion flux of species, kg/m^2s
K	Kinetic energy of turbulence, m^2/s^2
L	Length scale of Turbulence, m
Le_i	Lewis number $Le_i = \frac{k}{\rho\, c_p D_{i,m}}$
M	Metabolic rate, W/m^2
M_t	The turbulent Mach number
N	The ISO class number
N_{faces}	Number of faces enclosing cell
Pr	$Pr = C_p\mu / k$ Molecular Prandtl number
Pr_t	The turbulent Prandtl number for energy
R_i	The net rate of production of species *i* by chemical reaction, kg/m^3s

Sc	Molecular Schmidt number $Sc = \nu / D_{im}$
Sc_t	Turbulent Schmidt number
S_φ	The source term of the general form of conservation equation
$\vec{u}$	The flow velocity vector, m/s
$\vec{u}_g$	The grid velocity of the moving mesh, m/s
$\boldsymbol{u_i}$	The fluctuating velocity component, m/s
$\overline{\boldsymbol{u_i}}$	The mean velocity component, m/s
u_j	Mean velocity component, m/s
U_p	Particle velocity vector, m/s
Y_M	The contribution of the fluctuating dilatation to the overall dissipation rate

GREEK LETTERS

P	Density of the fluid, kg/m^3
ρ_p	Density of airborne particles, kg/m^3
τ_{ij}	The stress tensor, N/m^2
δ_{ij}	Kronecker delta
μ_{eff}	Effective turbulent viscosity
$\Gamma\varphi$	The diffusion coefficient
μ_t	Turbulent viscosity, kg.m/s
ϵ	Turbulence dissipation rate, m^2/s^3
β	Coefficient of thermal expansion, K^{-1}
δV_j	The volume swept out by the control volume face j, m^3
Φ_f	Value of Φ convected through face *f*
$\nabla\Phi$	Gradient of Φ
Λ	The molecular mean free path factor
σ_ϵ	The turbulent Prandtl numbers for ϵ
σ_K	The turbulent Prandtl numbers for k
$-\rho\overline{u_i^{'}u_j^{'}}$	Reynolds stresses term

ABBREVIATIONS

ACH	Air changes per hour
AIIR	hospital-acquired infection
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD	Computational Fluid Dynamics
CV	Control volume
AIA	American Institute of Architects
DV	Displacement ventilation
RSV	respiratory syncytial virus
HCW	Healthcare workers
HEPA	High Efficiency Particulate Air
HVAC	Heating ventilation and air conditioning
TB	tuberculosis
IAQ	Indoor air quality
LES	Large Eddy Simulation
ISO	International Organization for Standardization
LRN	low-Reynolds-Number
$\mu g/m^3$	Micrograms per cubic meter
µm	Micrometer
MLR	Multiple linear regressions
MV	Mixing ventilations
mg/m^3	Milligrams per cubic meter
NASA	National Aeronautics and Space Administration
Pa	Pascals
PISO	Pressure-Implicit with Splitting of Operators
RANS	Reynolds-averaged Navier-Stokes
RSM	Reynolds Stress Model
RH	Relative Humidity
RNG	Re-Normalization Group
SIMPLE	Semi-Implicit Method for Pressure-Linked Equations
ULPA	Ultra Low Particulate Air
W	Watt
W/m^2	Watt per m^2

ABSTRACT

The design of air conditioning system in ward room plays a very important role, not only in providing the thermal comfort, but also to ensure the effectiveness of the infection control system inside the ward room. The infection control system has many components that ensure preventing of any biological contaminations that might be introduced to the ward space because of the presence of infected patients. The locations of the air conditioning inlet diffusers and outlet grills prescribe the flow pattern inside the ward space. As the flow pattern inside the ward changes, the probability of biological contamination spreading from one bed area to the neighboring beds changes.

This study determines the optimum locations of the air inlet diffusers and air suction grills to achieve the lowest probability of the spreading of biological contaminations between bed areas. Since the biological contamination is mostly introduced to the ward during the patients breathing, it is appropriate to use the spreading of other breathing products as a measure of the spreading of the biological contaminants. Accordingly, the spreading of $C0_2$ generated during patient breathing is chosen as a measure of the spreading of biological contamination introduced.

This study uses the commercially available software ANSYS-FLUENT to perform the required analysis. ANSYS-FLUENT is a computational fluid dynamics (CFD) program that is based on finite volume method. Fluent solves the continuity, momentum and energy governing conservation equations to predict the flow field inside the computational domain. Species conservation equation is also resolved to determine the spreading pattern of the breathing CO_2. $k - \varepsilon$ turbulence model is used to take into account the effect of turbulence on the flow pattern .

Before using CFD as a design tool, the CFD program is validated against experimental data available in the open literature. Therefore, this study uses the experimental data from the work of Sarkar et al. [48] and Zhang, and Chen [49] to authenticate the current numerical results of (ANSYS 15.0) code by comparing temperature and air velocities. It was founded that there is a good agreement between the CFD results and the experimental results.

This thesis studies four cases with different outlets and inlets. For the first case, both the outlet and inlet at ceiling. There are two outlets at the sides of ceiling and the inlet at the middle. The second one, only the inlet changed from single jet to six separated jets also at the middle of the ceiling. Third case the inlet is the same as second case but the outlet replace by using multi-outlets behind and above each bed. The fourth case has the same outlet but the inlet became behind and below each bed.

The results shows that for all cases the temperature, the relative humidity, and the air velocities have acceptable values and distribution as they are within the accepted ranges. Regarding the spreading of the breathing CO_2, case 3 configuration has eliminated the possibility of the spreading of the breathing outflow gases from one bed area to another. Therefore, case 3 configuration provides the optimal configuration to reduce the portability of the spreading of biological contamination resulting from patients breathing activity.

Chapter 1
Introduction

1.1 General

Hospitals and other health care services are condemning domains that require ventilation for solace and to control unsafe outpouring for patients, workers and visitors. Indoor air quality is more condemning in health care spaces than in most other indoor domains due to the truth that many unsafe microbial and chemical agents existing and due to the increased tendency of the patients to communicable diseases. Healthcare regulars are at a maximal risk of contagion due to the constant insinuations in the work climate.

The health-care climate contains a diverse population of microbes, but only a little are momentous pathogens for liable humans. Microorganisms are present in huge records in moist, untreated environments, but some also can keep it up under dry circumstances. Even though pathogenic microbes can be detected in air and water and on fomites, assessing their task in causing infection and sickness is complex, [1].
Even though an excess of guiding principle on the aeration of health care services have been in print, the huge bulk of these are anxious with expert facilities, such as operating theatres, isolation rooms, and bronchoscopy suites, where the risks associated with the airborne transmission of infection are well characterized. In contrast, strategy regarding the airing of general ward spaces, patient rooms, and intensive care wards are much sparser and often hazy in nature. For example, in the United Kingdom, National Health Technical Memorandum HTM 2025(Design Considerations, Ventilation in Health Care Premises) makes modest orientation to the airing of medical spaces other than operating theatres certainly, other than cheering the use of full new air systems, HTM 2025 specifies no criteria for the airing of ward spaces. In an era where hospital-acquired infection (HAI) is a major global difficulty, this may appear to be an astounding lapse. Ward airing could play a vital function in scheming the extend of HAI, although there is a usually detained sight that most nosocomial infections are transmitted by the get in touch with route (ie, through the hands of health care workers). Certainly, only a little nosocomial diseases of a bacterial or fungal etiology, such as tuberculosis (TB), legionnaire's disease, and pulmonary aspergillosis, are willingly accepted as being transmitted by an airborne path. Consequently, ward airing systems are generally specified in terms of providing patient comfort and minimizing energy expenses, rather than for medical reasons. In short, ward airing is apparent as having little impact on the broadcast of HAI and thus is not thoroughly specified. In spite of this, there is rising proof representing that airborne pathogens may play a greater function in the stretch of infection inside wards than ever expected. If this is the case, then the potential of ward ventilation systems to control infection may have been really underestimated, and there is a need to re-examine the basis on which such systems are specified [2].

Respiratory infections can be acquired from contact to pathogens contained either in droplets or in droplet nuclei. Exposure to microbes in droplets (e.g., through aerosolized oral and nasal secretions from infected patients), [3] constitutes a form of straight contact broadcast.

When droplets are shaped through a sneeze or cough, a blur of infectious particles >5 μm in size is barred, consequential in the potential exposure of susceptible persons within 3 feet of the source person, [4]. Examples of pathogens spread in this manner are influenza virus, rhinoviruses, adenoviruses, and respiratory syncytial virus (RSV). Because these agents above all are transmitted straight and because the droplets tend to fall out of the air quickly, measures to control air flow in a health-care facility (e.g., use of negative pressure rooms) usually are not indicated for preventing the increase of diseases caused by these agents.The increase of airborne infectious diseases via droplet nuclei is a form of roundabout broadcast [5, 6].

Key areas where enhanced indoor air quality can be effectual in better patient health comprise:

- Clinical pharmacies
- Operating rooms
- Emergency rooms
- Intensive care units
- Airborne infection isolation rooms
- Ward rooms

Enhanced organization of indoor air quality and air allocation reduces the danger to patient health, and reduces the cost of costly pills treatments.

All of these truths make it advantageous to conduct the present work about hospital Heating, Ventilation, and Air conditioning (HVAC) system design. Computational fluid dynamics analysis techniques permit a study of the airflow, contaminants, and temperature distribution and the optimization of air release to attain superior infertility in risk-affected areas.

1.2 Factors Affecting Occupant Comfort and Productivity in Healthcare Facilities

Thermal comfort is a state of mind, which expresses satisfaction with the nearby surroundings, most vital factors influencing thermal comfort are:

Environmental factors:

- Air temperature
- Air speed
- Relative humidity
- Air quality

Other factors:

- Activity stage
- Psychological factors: such as mental effort
- Noise

Achieving thermal comfort for most occupants of buildings or other enclosures is a major objective of HVAC design engineers.

1.3 HVAC for Healthcare Facilities

Indoor air quality is of dominant significance for human comfort and health. Air, whether it is from exterior or re-circulated within the area, acts as a vehicle for airborne contaminants brought in by people movement. Since many of these airborne contaminants are injurious their elimination is essential on medical, legal, social or financial foundations.

A diversity of airborne infections in disposed hosts can result from exposures to microbes unrestricted into the air when environmental reservoirs (like water, dust, and decaying organic material) are disturbed. Once these resources are brought inside to a health-care facility by any of a number of transporters (like human, air, water, and equipment), the attendant bacteria can reproduce in a variety of indoor ecological niches and, if afterward disbursed into the air, serve as a resource for airborne health-care–linked infections.

Basic Components and Operations

HVAC systems in health-care conveniences are designed to a) keep up the indoor air temperature and relative humidity at relaxed levels for staff, patients, and visitors; b) odors control; c) get rid of impure air; d) ease air-handling necessities to protect susceptible workers, patients, and visitors from airborne health-care–associated pathogens; and e) decrease the danger for spread of airborne pathogens from infected patients, [7].

The American Institute of Architects (AIA) has published strategy for the design and structure of innovative health-care facilities and for renovation of presented facilities. These AIA strategy gather indoor air-quality standards (e.g., ventilation rates, humidity levels, temperature levels, pressure relationships, and minimum air changes per hour (ACH) specific to every region in health-care facilities (like, operating rooms, laboratories, patient-care areas, and support departments), [7]. Figure 1.1 shows Plan of a ventilation system at occupied space.

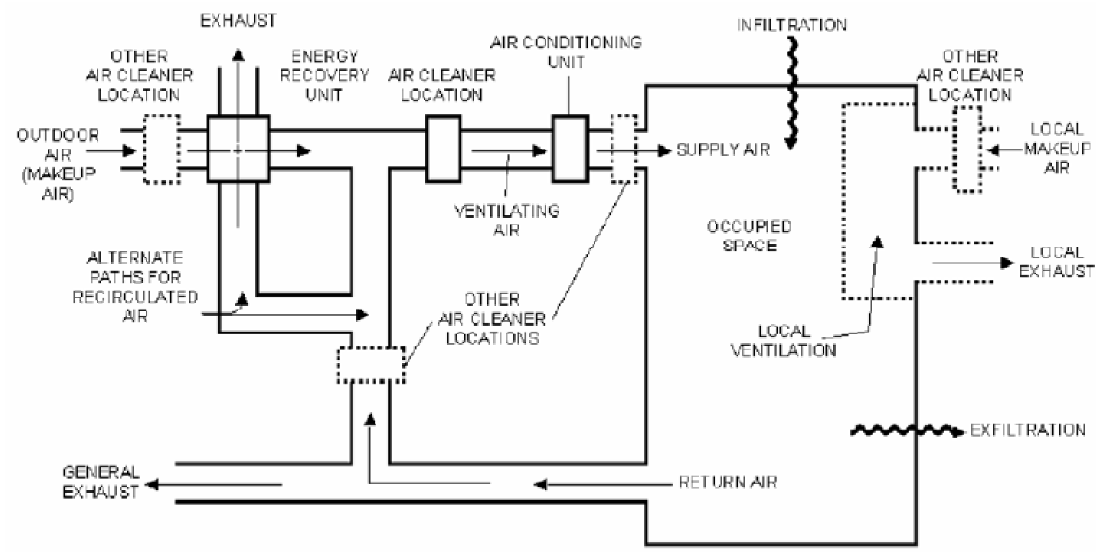

Figure 1.1 Plan of a ventilation system, [8, and 9].

1.4 HVAC Parameters of Design

Temperature and humidity are two critical elements of the conditioned air. Once exterior air passes across a small- or medium-efficiency filter, the air yield to conditioning for temperature and humidity control before it passes through high-efficiency filtration.

1.4.1 Temperature, humidity, and air change rates

1.4.1.1 Temperature

HVAC designs in health-care services are frequently single-duct or dual-duct designs. A single-duct design spreads cooled air (55°F [12.8°C]) during the structure and uses reheat boxes which are thermostatically controlled situated in the terminal ductwork to heat the air for single or several rooms. The dual-duct design consists of two parallel ducts, one of them with a chilly air path and the other one with a warm air path. Every room or set of rooms contain a mixing box which mixes the two air paths to attain the wanted temperature. Standards of temperature are specified as either an elementary temperature or a range, relying on the particular health-care region. Cool temperature standards (68°F–73°F [20°C–23°C]) commonly are related with operating rooms, clean workrooms, and endoscopy suites [8]. A hotter temperature (75°F [24°C]) is desired in spaces requiring larger degrees of patient comfort. Most other spaces take a temperature range of 70°F–75°F (21°C–24°C),[10]. Other temperatures may be desired in limited spaces relying on individual situation throughout patient need (like, cooler temperatures in operating rooms during specialized operations).

1.4.1.2 Humidity

To compute diverse physical properties of the combination of water vapor and air, four gauges of humidity are used. Relative humidity is the most familiar of these, which defined as the ratio of the quantity of water vapor in the air to the quantity of water vapor air can hold at that temperature, [11]. The other gauges of humidity are specific humidity, dew point, and vapor pressure, [11].

Relative humidity eliminates the percentage of saturation. The air is called saturated at relative humidity 100%. For most spaces inside health-care facilities, the nominated comfort range is 30%–60% relative humidity, [7, and 9]. When relative humidity levels >60%, in addition to being uncomfortable, this sponsor fungal expansion, [12]. Humidity values can be controlled by any of two criteria, [13]. In first criterion, a water-wash unit, water is splashed and the filtered air takes the drops; additional heating or cooling of this air detects the humidity levels. The second criterion is via water vapor shaped from steam and added to filtered air in humidifying boxes. Cool-mist humidifiers should be averted, since they can publicize aerosols containing allergens and bacteria, [14].