CHAPTER 2

LITERATURE REVIEW

This chapter deals with the literature survey in connection with Indoor air quality. The promising parameters for better Indoor air quality and possible modeling and optimization techniques that could be used for identifying optimal Indoor air quality have been discussed. The mostly used prediction and optimization techniques to get better indoor air quality in Airconditioned spaces were discussed. The numerical analysis of the Airconditioned space to study the human comfort and ventilation effects were also conversed in this Chapter.

2.1 INDOOR AIR QUALITY AND HUMAN COMFORT

Indoor air is a dominant exposure for humans. Indoor air was believed to be a major environmental factor for more than a hundred years, from the start of the hygienic revolution, around 1850, until outdoor environmental issues entered the scene, and became dominant around 1960. There is mounting evidence that exposure to IAQ is the cause of excessive morbidity and mortality. Poor IAQ is a main cause for allergies, other hypersensitivity reactions, airway infections, and cancers. Among which allergies, airway infections and sick building syndrome are associated with, a low ventilation rate and plasticizers (Sundell et al 2004).

Kong Dequan et al (2008) introduced the main category and source of air pollutions that influences modern building indoor environment and
analyzed the main influencing factors on indoor IAQ of the airconditioning system. Indoor air quality can be analyzed from three points of view: the human, the indoor air of the space and the sources contributing to indoor air pollution. Standards currently in use mainly address the indoor air of the space.

Müller et al (2011) analyzed potential sources of car indoor pollution and presented factors that affect indoor air quality in cars. The methods and factors that may improve indoor air quality in cars when used correctly were also reported by this researcher.

Scott et al (2011) developed a predictive model for vehicle air exchange rate. The research showed that air exchange rate increases with vehicle speed due to pressure differences/ turbulence around the vehicle. But for a given vehicle speed the air exchange rate is nearly constant and the CO₂ concentrations inside the car will eventually reach an equilibrium value.

With the improvement of standard of living, Airconditioning has widely been applied. However, health problems associated with Airconditioning systems and indoor air quality appear more frequently. Yu et al (2009) appraised on Airconditioning systems and indoor air quality control for human health. The problems in the existing research were summarized. Further studies were suggested on Airconditioning systems for indoor air quality control in healthy indoor air environment.

The role of human occupancy as a source of indoor biological aerosols is poorly understood. Size-resolved concentrations of total and biological particles in indoor air were quantified in a classroom under occupied and vacant conditions. Per-occupant emission rates were estimated by Qian et al (2012) through a mass-balance modeling approach, and the
microbial diversity of indoor and outdoor air during occupancy was determined via rDNA gene sequence analysis.

Carbon dioxide (CO₂) concentration is the major pollutant which affects the Indoor Air Quality. Andrew Kusiak et al (2009) used the CO₂ concentration as the major indoor air quality index and expected room occupancy schedule to get optimal solutions by multi-objective optimization leading to reduced CO₂ concentration and energy costs. The optimized ventilation schedules result in energy savings and maintained an acceptable level of indoor CO₂ concentration.

Usha Satish et al (2012) experimentally found how human decision making was affected by increased levels of indoor CO₂ concentrations. At 1,000 ppm CO₂, compared to 600 ppm, performance was significantly reduced to six out of nine metrics of decision-making. At 2,500 ppm CO₂, compared to 600 ppm, performance was significantly reduced in seven of nine metrics.

High concentration of carbon dioxide (CO₂) can cause exhaustion and drowsiness in enclosed spaces, especially in those environments with very limited spaces, such as aircraft cabins. The phenomenon that CO₂ concentration keeps high due to the eddy airflow in some certain zones known as CO₂ lockup was simulated using computational fluid dynamics by Mengxi Li et al (2015). These researchers presented numerical study on the CO₂ lockup phenomenon in aircraft cabins and suggested methods to overcome this problem.

Feng-Chyi Duh (2015) investigated effects of air conditioning on the quality of air in parked cars and moving cars. Carbon dioxide, carbon monoxide, volatile organic compounds, and formaldehyde concentrations were measured. The results showed that simply changing the air conditioning
system from internal circulation to external circulation reduces carbon dioxide concentrations by more than 50%.

Ajimotokan et al (2009) presented the influence of indoor environment on workers’ health, comfort and productivity, conducted at a beverage bottling facility in Ilorin, Nigeria. A three-step regimen method was used to achieve the desired solution. Evidence from the review of observed complaints, depicted that continual environmental stress drain, physical and mental resources and ultimately affect human performance and decrease productivity. Recommendations were given to improve and maintain good indoor environmental quality specifically through good indoor air quality.

To make clear the realities of indoor air (IA) pollution in lecture rooms of Tottori University in Japan, Manoj Arya et al (2011) studied air quality by monitoring the CO₂ level, an index of indoor air pollution. The CO₂ level was monitored at 5-min intervals during 2 or 3 consecutive 90-min lectures using an infrared ray absorption type CO₂ monitor. Based on the observed levels for 90 min, the ventilation rate calculated (times of operating the ventilation fan), and estimated CO₂ level change in ventilated and non-ventilated rooms for a 90-min lecture.

The indoor air quality (IAQ) of hotels is rarely investigated and reported. Wilcochan et al (2008) conducted a study aimed at examining the air quality in newly opened hotels. A field test was carried out in each of the eight sampled hotels, investigating both indoor and outdoor air qualities. Major air pollutants including individual volatile organic compounds (VOC) and total volatile organic compounds (TVOC), as well as physical background parameters such as air temperature (Ta), relative humidity (RH), and ventilation rate were investigated. The results showed that most of the hotels were unable to provide a completely healthy indoor environment. On comparing with findings of similar studies, this study reveals that in terms of
air quality, new hotels were more polluted than older hotels and residential buildings. The dominant pollution sources came from indoor, rather than ambient environment.

Ke-wei et al (2007) conducted air sampling and analyses of volatile organic compounds (VOC) inside vehicles have been determined in a new vehicle and two old vehicles under static conditions. It was reported that the types and quantities of VOCs varied considerably according to various kinds of factors, such as vehicle age, vehicle model, temperature, air exchange rate, and environment airflow velocity.

Indoor air quality assessment was conducted by Shelly L Miller et al (2009) on 100 homes of Mexican immigrants in Commerce City, Colorado, an urban industrial community north of Denver. Carbon monoxide (CO) and carbon dioxide (CO2) were measured for 24 hour inside the main living area and outside of the homes. The results indicated that the source of indoor pollution were occupants and their activities, excluding smoking and cooking. Mean indoor CO2 and CO levels were 1170 and 2.4 ppm, respectively.

John Swift et al (2007) describes how HVAC systems interact with the building indoor and outdoor environment, and includes sections dealing with indoor environmental quality, cooling tower systems and chemical water treatment, acoustics, and the science of designing healthy buildings. The newly revised ASHRAE Green Guide was analyzed particularly as it relates to the topic of indoor environmental quality.

The indoor air quality (IAQ) was measured in newly built Korean apartments before and after occupancy in a survey of 158 residences in 24-apartment complexes nationwide by Wan-Je Jo et al (2009). Factors that might affect pollutant concentration, such as temperature, humidity, housing
size, and duration of occupancy, were analyzed in relation to the measured concentrations. Average pollutant levels were consistent with the recommended standards; however, pollutant levels in some apartments exceeded the standards. It was found that the concentrations of formaldehyde and toluene often exceeded the guidelines.

The results show that the pollution concentration was generally proportional to temperature and humidity, but that, in some cases, the concentration measurements were inversely proportional to these two factors, and in a few others the relationship between these factors was not clear. Indoor air pollution readings were highest in the 30-pyeong apartments (unit for the size of rooms or buildings in Korea equivalent to 3.3058 m²), followed by 10-, and 20-pyeong residences.

Bacterial contamination in indoor and outdoor air of two metro stations (Imam Khomeini and Sadeghiyeh stations) in Tehran subway system was investigated by Naddafi et al (2011). In this study, three sampling locations were selected in each station. Also, sampling was conducted in indoor air of two types (old and new) of trains. Results showed that bacterial concentrations in indoor air were higher than the outdoor air; also the bacterial counts correlated significantly with number of the passengers and air temperature.

Huanxin Chen et al (2003) has investigated IAQ in train compartments using a questionnaire, and analyzed the result for different types of train compartments. It was concluded that fresh air is the main factor that affects indoor environment. The results of this investigation revealed that passengers were not satisfied with IAQ in train compartments for the odors. The passengers reported symptoms like headache, dizzy, sick, etc.
Ventilation system is widely used to control indoor air quality (IAQ) in subway stations. However, improper ventilation control strategy not only leads to unnecessary hazardous pollutants accumulation but also to energy losses. Therefore an accurate predictive model is needed to control IAQ effectively as well as to minimize the energy consumption in underground subway stations. Level of outdoor air pollutants must be considered for the design of ventilation control system as there are nonlinear dynamic relations.

Gilda Rusu-Zagar et al (2009) studied indoor air quality (IAQ) focused into a metallurgic industrial hall. A model named INPOLL for computing the time evolution of concentrations of various air pollutants in closed working areas was carried. The model used partition of the working unit in a convenient number of cells with known transfer and ventilation air fluxes. A time-dependent injection of pollutants occurring in various sites of the working space determines the subsequent evolution of pollutant concentrations in all the compartments of the partition. Starting from some given set of background concentrations, the model predicted the values of the pollutant concentrations in each cell, at any time from the start. By varying the model parameters like the air currents for ventilation or the time delay between furnace discharges one can obtain a process optimization from the point of view pollutant concentrations.

Andrew Kusiak et al (2010) developed a data-driven approach for modeling indoor-Air quality (IAQ) sensors used in heating, ventilation, and airconditioning (HVAC) systems. The IAQ sensors considered in his work measured three basic parameters, temperature, CO₂, and relative humidity. Three models predicted values of IAQ parameters are built with various data mining algorithms. These models built with data mining algorithms served as
virtual IAQ sensors in buildings and be used for on-line monitoring and calibration of the IAQ sensors.

The same researcher presented data-driven approach for minimization of the energy to airconditioning in a typical office-type facility. Eight data-mining algorithms were applied to model the nonlinear relationship among energy consumption, control settings (supply air temperature and supply air static pressure), and a set of uncontrollable parameters. These four models are integrated into an energy optimization model with two decision variables, the set point of the supply air temperature and the static pressure in the air handling unit. The model was solved with a Particle Swarm Optimization (PSO) algorithm. The optimization results have shown the total energy consumed by the heating, ventilation, and Airconditioning system is reduced by over 7%.

Ventilation effectiveness is an indicator of the quality of supply air distribution in ventilated rooms. It is a representation of how well a considered space is ventilated compared to a perfect air mixing condition. Depending on pollutant properties and source position relative to the airflow, ventilation effectiveness can more or less successfully be used as an indicator of air quality and human exposure. Donghyun Rim et al (2010) conducted an experimental and numerical study that examines the relationship between ventilation effectiveness and particle concentration in typical indoor environments. The results exhibited that the relationship varies predominantly with airflow pattern and particle properties. Fine particles (1mm) follow the airflow pattern more strictly than coarse particles (7mm), and the high ventilation effectiveness indicates better removal of fine particles than coarse particles.

The occupant’s exposure to pollutant depends on the ratio of time occupant stays at the workstation over total time he/she stays in the room.
This ratio is named occupied density (OD). Stefano et al (2007) developed an index, using a modified definition of OD, to compare and quantify the variation in terms of inhaled pollution by occupant in a room with personal ventilation (PV) in combination with a total-volume ventilation system. The PV system decreases the pollutant concentration mostly in the microenvironment at the workstation. It can also increase the contaminant in other zone of the room. The index is applied to data collected during full-scale room measurements. The results showed that the index can be used at the design stage for assessment the benefit of PV when applied in practice for office buildings with different OD. If the occupied density is lower than 0.5 the use of displacement ventilation alone will be advantageous with regard to human-produced contaminates in comparison when it is combined with PV system.

2.2 MULTI OBJECTIVE GENETIC ALGORITHM (MOGA)

Velimir et al (2009) described the use of genetic algorithms (GAs) for operating standard HVAC systems (HVAC—heating, ventilation and airconditioning) in order to optimize performance, primarily with regard to power saving. Analytic optimization procedures are widely used in other fields of engineering, but they are difficult to operate within HVAC systems, because the range of the research is usually too broad, the problems are not linear but rather discontinuous, and they mostly have complex limitations. The researcher conducted GA simulation in order to demonstrate how much power can be saved by using the suggested method of CO2 concentration control in a standard HVAC system.

Jianfeng Qian et al (2006) illustrated the use of a heat pipe as a heat-reclaiming device significantly influencing the Airconditioning system. The heat transfer model of the uniform annular fin heat pipe was analyzed in airconditioning environment. It established functions of the fin structure
parameters such as height spacing and thickness of the fin when the volume of fin is the smallest under unit temperature difference and unit quantity of heat. Genetic algorithm was used in this study to optimize the model of the uniform annular fin heat pipe.

Jonathan Wright et al (2008) described the experimental results for the optimization of a two-zone HVAC system of a building located in a continental climate. The goal of the optimization was to find a feasible system design that operated with the minimum system capacity at each load condition. The optimization method used in this research was based on Genetic Algorithm search method. The robustness of the optimization was examined through the consistency of the design solutions found from multiple runs of the algorithm. The results indicated that given two runs of the algorithm, there was a high probability of finding a system design that has a performance comparable to existing system configurations.

Kolokotsa et al (2009) presented a model-based predictive controller, combined with a Building Energy Management System (BEMS). The overall system predicted the indoor environmental conditions of a specific building and selects the most appropriate actions so as to reach the set points and contribute to the indoor environmental quality by minimizing energy costs.

Multi-objective formulations are realistic models for many complex engineering optimization problems. In many real-life problems, objectives under consideration conflict with each other, and optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to the other objectives. A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution. Abdullah Konak et al (2006) presented describing genetic algorithms
(GA) developed specifically for problems with multiple objectives. They differ primarily from traditional GA by using specialized fitness functions and introducing methods to promote solution diversity.

Intelligent building technology for building operation was developed and validated by Nabil Nassif et al (2005). The optimization process using a multi-objective genetic algorithm (MOGA) will permit the optimal operation of the building's mechanical systems when installed in parallel with a building's central control system. HVAC system steady-state models were developed and validated against the monitored data of the existing VAV system were used for energy use and thermal comfort calculations. The proposed optimization process is validated on an existing VAV system for two summer months. Many control strategies applied in a multi-zone HVAC system were also tested and evaluated for one summer day.

Carbon-dioxide (CO₂) based demand controlled ventilation (DCV) offers the potential for more energy efficient building ventilation compared with constant ventilation rates based on design occupancy. A number of questions related to CO₂ DCV exist regarding energy benefits, optimal control strategies, and indoor air quality impacts for contaminants with source strengths that are independent of the number of occupants. In order to obtain insight into these issues, Persily et al (2003) performed a simulation study in six commercial and institutional building spaces. The results depended on occupancy patterns, design ventilation rate and ventilation system operating schedule as well as assumed contaminant source strengths and system-off infiltration rates. In these simulations, CO₂ DCV resulted in significant decreases in ventilation rates and energy loads accompanied by increased indoor CO₂ and Volatile Organic Compound (VOC) concentrations.

Heating, ventilating, and airconditioning (HVAC) systems comprise nearly one third of annual household energy consumption. HVAC
energy use can be reduced by applying controls. Wemhoff (2010) in his study applied a novel control method on a system with arbitrary steady-state and transient load distributions. The new method uses multi-dimensional interpolation between optimized control configurations for various steady-state load distributions. Demonstration of the new method on a two-room HVAC system predicted power savings for an arbitrary steady load that was nearly equivalent to that using a Variable-AirVolume (VAV) with chiller modulation. The average transient temperature deviation from set point using the new method is slightly better than that using VAV with chiller modulation.

Malcolm Owen Nga et al (2011) presented a case study for an American elementary school gymnasium in order to compare the implementation of CO₂ based demand control ventilation (DCV) under the old and new ventilation standards (i.e. ASHRAE 62 and 62.1) in terms of control strategies involved, the resulting energy savings, and indoor air quality associated with each strategy. The results indicated that, compared to the existing fixed ventilation rate strategy at which the ventilation rate is always 5% of the total supply air flow, a cooling coil energy savings of 0.03% and 1.86% can be achieved using an occupancy detection control strategy under the new ASHRAE 62.1 and old ASHRAE 62 respectively without compromising thermal comfort and indoor air quality.

Ventilation is ambiguously related to the energy saving rationale originating from the mitigation of global warming. Since it makes up for about half of the energy consumption in well-insulated buildings, it is an attractive target for energy saving measures. But reducing ventilation rates has unwanted repercussions on the indoor air quality. Two main strategies have been developed to reconcile these seemingly opposing interests: heat recovery and demand control ventilation.
Laverge et al (2011) focused on the energy saving potential of demand controlled mechanical exhaust ventilation in residences and on the influence such systems may have on the indoor air quality. Four approaches to demand based control were tested and reported. Both energy demand and exposures are reported and compared to the results for a standard, building code compliant, exhaust system, operating at continuous flow rates. The sensitivity of the control strategies to environmental and user variations is tested using Monte-Carlo techniques. Under the conditions that were applied, reductions on the ventilation heat loss of 25–60% were found, depending on the chosen control strategy.

Mendes et al (2003) developed a simulation tool based on the MATLAB computational environment for building temperature performance analysis with automatic control. The tool contains mathematical models for buildings, HVAC (Heating, Ventilation and Airconditioning) systems, sensors, weather data and control algorithms. The building mathematical model is described in terms of state space variables, with a lumped approach for the room air governing equations – energy and mass balances. Five control strategies were applied to HVAC systems, integrated to building zones with a simulation example that illustrates the use of the MATLAB tool.

Roberto Z Freirea et al (2008) worked on the study of indoor thermal comfort control problem in buildings equipped with HVAC (heating, ventilation and airconditioning) systems. The occupants’ thermal comfort sensation was addressed by the comfort index known as PMV (predicted mean vote) and by a comfort zone defined in a psychrometric chart. The first set of strategies is related to the thermal comfort optimization and the second one includes energy consumption minimization, while maintaining the indoor thermal comfort criterion at an adequate level. The methods are based on the model predictive control scheme and simulation results are presented in two
case studies. The results validated the proposed methodology in terms of both thermal comfort and energy savings.

Bowen et al (1990) designed IAQES (Indoor Air Quality Testing and Evaluation Expert System), a rule-based expert system application that diagnoses and suggests resolutions for common Air quality complaints that occur in office buildings. The IAQES also a part of larger Air quality management package that provided services, such as ventilation system design aids and online Air quality databases. The IAQES served as a training tool for building maintenance personnel to learn and recognize the cause of common Air quality problems.

Du Xiaogang et al (2008) presented the studies on ventilation in guest room in hotel. To Airconditioning system with fan and fresh air, the pollutants indoor are mainly removed by fresh air. Enlarging the fresh air volume can develop the indoor air quality, but goes against to the energy saving. The researcher simulated the CO₂ concentration indoor under different fresh air volume when the bathroom door opens and closed. The result indicated that only enlarging the fresh air volume affected the IAQ slightly, and exhaust fan can satisfy the ventilation indoor whether the bedroom door opens or closed.

Heating, Ventilating and Airconditioning (HVAC) Systems are usually implemented for maintaining satisfactory comfort conditions in buildings. The design of Fuzzy Logic Controllers for HVAC Systems is usually based on the operator's experience. Alcala et al (2006) presented a study of how several tuning approaches can be applied and combined with a rule selection method to obtain more compact and accurate Fuzzy Logic Controllers concerning energy performance and indoor comfort requirements of a HVAC System. Rule selection methods directly obtain a subset of rules from a given fuzzy rule set, removing inefficient and redundant rules and,
thereby, enhancing the controller interpretability, robustness, flexibility and control capability. This study has been performed considering a physical model of a real test environment.

Mohammad Abdel Kareem Jaradat et al (2009) proposed indoor air quality control (IAQ) based on fuzzy logic in natural ventilated indoor environments where no other ventilation approaches are installed or can be installed due to space limitation or other reasons. Four distributed sensors inside the indoor environment were used to provide the basic measurable inputs to the fuzzy system. The inputs were carbon dioxide (CO₂), carbon monoxide (CO), humidity (H₂O) and odors concentrations inside the indoor environment. The fuzzy logic output provided the required control command to the DC-motor connected to the fan by determining the necessary duty cycle to the PWM module. The simulation results have confirmed the ability of the fuzzy system to handle the ventilation problem at critical situations compared to naturally ventilated, indoor environment.

Few thermal comfort studies had reported that some discrepancies were observed in ASHRAE Standard 55 and ISO 7730 application for Naturally Ventilated (NV) buildings in hot and humid tropical climate. These standards failed to take into considerations tolerance and different perception of thermal comfort from different environmental setting. Henry Feriadi et al (2003) in his study used fuzzy logic approach to model an appropriate Thermal Comfort (TC) standard for tropical naturally ventilated houses. The complexities of the human cognitive process and the vagueness of linguistic expression are considered. Fuzzy logic was used as a mathematical model to allow representation of human decision and evaluation processes in algorithmic form. A detail exposition of the application which combined the linguistic approach to the optimization under multiple thermal condition criteria was presented.
Zhang Huaguang et al (2002) presented decentralized nonlinear adaptive controller (DNAC) for a heating, ventilating, and airconditioning (HVAC) system capable of maintaining comfortable conditions under varying thermal loads. In this scheme, an HVAC system was considered to be two subsystems and controlled independently. The interactions between the two subsystems are treated as deterministic types of uncertain disturbances and their magnitudes are supposed to be bounded by absolute value. The decentralized nonlinear adaptive controller (DNAC) consists of an inner loop and an outer loop. The inner loop is a single-input fuzzy logic controller (FLC), which is used as the feedback controller to overcome random instant disturbances. The outer loop is a Fourier integral-based control, which is used as the frequency-domain adaptive compensator to overcome steady, lasting uncertain disturbances. The global DNAC controller ensures that the system output vector tracks a desired trajectory vector within the system bandwidth and that the tracking error vector converges uniformly to a zero vector.

Heating, ventilating and Airconditioning (HVAC) system is a complex non-linear system with multi-variables simultaneously contributing to the system process. It poses challenges for both system modeling and performance optimization. Traditional modeling methods based on statistical or mathematical functions limit the system operation and management. Data-driven models have shown powerful strength in non-linear system modeling and complex pattern recognition. Sufficient successful applications of data mining have proved its capability in extracting models that accurately describe the relation of inner system.

Lu et al (2005) implemented a practical method to optimize in-building section of centralized Heating, Ventilation and Airconditioning (HVAC) systems which consist of indoor air loops and chilled water loops. First, through component characteristic analysis, mathematical models
associated with cooling loads and energy consumption for heat exchangers and energy consuming devices were established. By considering variation of cooling load of each end user, adaptive neuro-fuzzy inference system (ANFIS) was employed to model duct and pipe networks and obtains optimal differential pressure (DP) set points based on limited sensor information. A mix-integer nonlinear constraint optimization of system energy was formulated and solved by a modified genetic algorithm. The main feature this research is systematic approach in optimizing the overall system energy consumption rather than that of individual component. A simulation study for a typical centralized HVAC system was provided to compare the proposed optimization method with traditional ones. The results showed that the proposed method indeed improves the system performance significantly.

Different applications of evolutionary computation can be found in business, marketing medical and manufacturing domains. Fan Tang (2010) applied the evolutionary computation approach in optimizing the performance of HVAC system. Energy saving can be achieved by implementing the optimal control set points with IAQ maintained at an acceptable level. A trade-off between energy saving and indoor air quality maintenance was also investigated by assigning different weights to the corresponding objective function. The major contribution of his research was to provide the optimal settings for the existing system to improve its efficiency.

Airconditioning load calculation is a control problem. The thermal model of the building will be linear if the model of the building, the weather conditions and occupational program are known in the design stage. Christian Ghiaus et al (2010) proposed an unconstrained optimal control algorithm which uses feed-forward to compensate the weather conditions and model predictive programming (MPP) for set-point tracking. MPP is obtained by modifying the dynamic matrix control (DMC), a variant of model predictive
control (MPC). The peak load depends on the set-back time of the indoor temperature: smaller the set-back time, larger the peak load, but smaller energy consumption.

2.3 RESPONSE SURFACE METHODOLOGY

The performance optimization of conventional HVAC systems may be handled by operation experience, but it may not cover different optimization scenarios and parameters in response to a variety of load and weather conditions. In this regard, it is common to apply the suitable simulation–optimization technique to model the system then determine the required operation parameters. The particular plant simulation models can be built up by either using the available simulation programs or a system of mathematical expressions.

Fong et al (2009) developed robust evolutionary algorithm (REA) and presented to tackle this nature of the HVAC simulation models. REA is based on one of the paradigms of evolutionary algorithm, evolution strategy, which is a stochastic population, based searching technique emphasized on mutation. The REA, which incorporates the Cauchy deterministic mutation, tournament selection and arithmetic recombination, would provide a synergetic effect for optimal search.

Lu Lu et al (2005) presented the global optimization technique for overall heating, ventilating and airconditioning (HVAC) systems. The objective function of global optimization and constraints were formulated based on mathematical models of the major components. All these models were associated with power consumption components and heat exchangers for transferring cooling load. The characteristics of all the major components were briefly introduced by models, and the interactions between them were analyzed to show the complications of the problem. According to the
characteristics of the operating components, the complicated original optimization problem for overall HVAC systems was transformed and simplified into a compact form ready for optimization.

### 2.4 FUZZY LOGIC

Providing thermal comfort and saving energy are two main goals of heating, ventilation and air conditioning (HVAC) systems. A controller with temperature feedback cannot best achieve the thermal comfort. This is because thermal comfort is influenced by many variables such as, temperature, relative humidity, air velocity, environment radiation, and activity level and cloths insulation. Yadollah Farzaneh et al (2008) in his study used Fanger’s predicted mean value (PMV) index as controller feedback. Thermal models of the cabin and HVAC system were developed. Evaporator cooling capacity was selected as a criterion for energy consumption. Two fuzzy controllers one with temperature as its feedback and the other PMV index as its feedback were designed. Results showed that the PMV feedback controller better controls the thermal comfort and energy consumption than the system with temperature feedback.

Yua et al (2009) discussed recent research on Airconditioning systems and indoor air quality control for human health. The problems in the existing research were summarized. A further study was suggested on Airconditioning systems and indoor air quality control for healthy indoor air environment. Rafael Alcal et al (2003) used genetic algorithms to develop smartly tuned fuzzy logic controllers dedicated to the control of heating, ventilating and airconditioning systems concerning energy performance and indoor comfort requirements. This problem has some specific restrictions that make it very particular and complex because of the large time requirements existing due to the need of considering multiple criteria (which enlarges the solution search space) and to the long computation time models require to
assess the accuracy of each individual. To solve these restrictions, a genetic tuning strategy considering an efficient multi criteria approach has been proposed. Finally, simulations and real experiments were compared determining the effectiveness of the proposed strategy.

Karunakaran et al (2009) developed a Variable Air Volume (VAV) system in highly preferred to be energy efficient Airconditioning scheme in modern heating, ventilation and airconditioning (HVAC) applications. The energy utilization of the VAV system has been experimentally investigated. Input data for fuzzy logic were zone temperature and duct static pressure. The output was supply air fan speed. Experimental results revealed that the energy saving potential of the VAV system was 27% at part load conditions, compared with the Constant Air Volume (CAV) systems. Experimental results express that the required thermal comfort was achieved using Fuzzy Logic Control based on the energy consumption characteristics, VAV systems are fast replacing CAV systems and are capable of maintaining the thermal comfort for varying load conditions. Fuzzy logic controllers (FLC) are highly preferred rather than conventional controllers since FLC exhibits reduced peak overshoot that is observed under transient conditions of the system. FLC has the capability of controlling the system precisely with the set points defined.

Optimized fuzzy controller was presented by Kolokotsa et al (2002) for the control of the environmental parameters at the building zone level in the Laboratory of Electronics of the Technical University of Crete. The occupants’ preferences were monitored via a smart card unit. Genetic algorithm optimization techniques were applied to shift properly the membership functions of the fuzzy controller in order to satisfy the occupants’ preferences while minimizing energy consumption.
Henry Feriadi et al (2003) used fuzzy logic approach to model an appropriate Thermal Comfort (TC) standard for tropical naturally ventilated houses. The complexities of the human cognitive process and the vagueness of linguistic expression are considered. Fuzzy logic is used as a mathematical model to allow representation of human decision and evaluation processes in algorithmic form. A detail exposition of the application which combined the linguistic approach to the optimization under multiple thermal condition criteria were presented in his research.

Living space climate regulation is a multidimensional problem having no unique solution. Conflicting requirement exists like minimization of energy consumption and the achievement of comfortable conditions. The definition of comfort is obscure and depends on considerably on the psychosynthesis of individuals living in space and on the activity they are engaged. Dounis et al (2001) structured a fuzzy system using the available measurements and the available actuators; the measurement includes fuzzification process and the defuzzification method. Particular attention is paid to the proper selection of the rules in the knowledge base and the design of the inference engine. Finally the system tested has shown a satisfactory performance.

Angelov et al (2000) proposed self-structuring fuzzy rule-based (FRB) models of HVAC components in his research work. Advantages of this method include model transparency (the linguistic rules are easily inspected), the possibility to insert expert knowledge into the model generation, and economy in computational effort in generating model output. The rules are extracted from the data without using a priori information about their structure. Modeling a range of ducted fans with different geometrical parameters and cooling coils are considered as illustrative examples. A
software program to implement the proposed approach has been developed in the MATLAB.

Rafael Alcala et al (2005) used weighted linguistic fuzzy rules in combination with a rule selection process to develop accurate fuzzy logic controllers dedicated to the intelligent control of heating, ventilating and airconditioning systems concerning energy performance and indoor comfort requirements. An efficient approach to perform rule weight derivation and rule selection, a genetic optimization process was developed. That allowed tuning of the system to be developed at the rule level. The above proposed technique was tested considering a physical model of a real test site.

2.5 ARTIFICIAL NEURAL NETWORK

Seung Chu Lee et al (2012) proposed a new nonlinear dynamic prediction model using external analysis in his research paper. Neural network was used to capture the nonlinearity between outdoor air quality and IAQ. After carrying out the nonlinear dynamic external analysis, partial least squares (PLS) method was used to predict PM10 concentration in underground station and the energy usage for the ventilation control. The proposed model applied to real-time IAQ data in D-subway station of Korea. The result showed that the prediction performances are greatly improved for PM10 concentration as well as energy usage of a ventilation system.

Further the researcher used data-driven approach for the optimization of a heating, ventilation, and airconditioning (HVAC) system in an office building. A neural network (NN) algorithm was used to build a predictive model. The NN-derived predictive model is then optimized with a strength multi-objective particle-swarm optimization (S-MOPSO) algorithm. The relationship between energy consumption and thermal comfort measured with temperature and humidity were discussed. The control settings derived
from optimization of the model minimize energy consumption while maintaining thermal comfort at an acceptable level. The solutions derived by the S-MOPSO algorithm point to a large number of control alternatives for an HVAC system, representing a range of trade-offs between thermal comfort and energy consumption.

Liang Zhou et al (2009) developed an optimization approach that encompassed two essential components: the first one was a high-resolution indoor airflow and heat transfer investigation so as to capture the distribution of assessment indices pertaining to thermal comfort, IAQ, and energy use; the other one was the integration of an economical optimization scheme. This simulation based optimization approach was developed with the ultimate goal of providing practical aid to conceptual ventilation design and regulation. In addition, it should offer flexibility to predict, evaluate, and compare a wide range of objectives and constraints. The path taken was a simulation-based optimization approach by using computational fluid dynamics (CFD) techniques in conjunction with genetic algorithm (GA), with the integration of an artificial neural network (ANN) for response surface approximation (RSA) and for speeding up fitness evaluations inside GA loop.

The heuristic techniques such as neural networks, support vector machine, and boosting tree have largely expanded to the modeling process of HVAC system. Evolutionary computation has rapidly merged to the center stage of solving the multi objective optimization problem Inspired from the biology behavior it has shown the tremendous power in finding the optimal solution of complex problem.

Hybrid of Artificial Neural Networks (ANN) and Fuzzy Inference Systems (FIS) have attracted the growing interest of researchers in various scientific and engineering areas due to the growing need of adaptive intelligent systems to solve the real world problems. ANN learns from scratch
by adjusting the interconnections between layers. FIS is a popular computing framework based on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. Tharwat et al (2010) developed a model based on three-layered neural fuzzy architecture with back propagation learning algorithm. Two objectives of the research were, to develop Fuzzy controller, scheme for the prediction of the changing for the NO₂ or SO₂, over urban zones based on the measurement of NO₂ or SO₂ over defined industrial sources. The second objective is to develop a neural net, NN; scheme for the prediction of O₃ based on NO₂ and SO₂ measurements.

Jin Woo Moon (2009) in his research developed an Artificial Neural Network (ANN)-based advanced thermal control method for creating more comfortable thermal environments in residential buildings. The proposed control method, which consisted of a thermal control logic and system hardware framework, was designed to improve residential thermal environments through the reduction of thermal imbalance in various rooms; the achievement of thermal comfort considering humidity or PMV as a control variable; and the reduction of overshoots and undershoots of air temperature, humidity and PMV using ANN-based predictive and adaptive control. The performance of developed control logics and system hardware was tested through computer simulation incorporating IBPT (International Building Physics Toolbox) and MATLAB, and through experiment. The study revealed that ANN-based predictive and adaptive control strategies created more comfortable thermal conditions than ones without in terms of increased comfort period of air temperature, humidity, and PMV. This improvement was through the reduced ratio and magnitude of overshoots and undershoots out of the specified comfort ranges.

Several data-driven prediction methods based on multiple linear regression (MLR), neural network (NN), and recurrent neural network (RNN)
for the indoor air quality in a subway station were developed and compared by Min Han Kim et al (2010). The RNN model predicted the air pollutant concentrations at a platform of a subway station by adding the previous temporal information of the pollutants on yesterday to the model. To optimize the prediction model, the variable importance in the projection (VIP) of the partial least squares (PLS) was used to select key input variables as a preprocessing step. The prediction models were applied to a real indoor air quality dataset from telemonitoring systems data (TMS), which exhibits some nonlinear dynamic behaviors have strong influence on the prediction performances of the models. The predicted result of the RNN model gives better modeling performance and higher interpretability than other data-driven prediction models.

The use of neural networks is popular in various building applications such as prediction of heating load, ventilation rate and indoor temperature. Significant is, that only few papers deal with indoor carbon dioxide (CO₂) prediction which is a very good indicator of indoor air quality (IAQ). Skön et al (2012) developed a data-driven modeling method based on multilayer perceptron network for indoor air carbon dioxide in an apartment building. Temperature and humidity measurements were used as input variables to the network. The results shown that predicting CO₂ concentration based on relative humidity and temperature measurements was difficult and needs more additional information.

The same researcher in another study applied continuous measurements and multivariate methods to investigate the effects of energy consumption on indoor air quality (IAQ) in a house. Measured data used in this study was collected over a period of fourteen months. Indoor parameters gathered were temperature, relative humidity (RH), the concentrations of carbon dioxide (CO₂) and carbon monoxide (CO) and differential air pressure.
In this study, self-mapping was applied to resolve the effects of energy consumption on indoor air quality. The results indicated that the cost implications in euros of heating and electricity energy vary according to the differential pressure, concentration of carbon dioxide, temperature and season.

2.6 GREY RELATIONAL ALGORITHM

Grey relational analysis (GRA) is useful for the multi-input, discrete data and uncertain experimental study. P.S. Kao et al (2003) applied the grey relational analysis for optimizing the electro polishing of 316L stainless steel with multiple performance characteristics. The processing parameters (temperature, current density, and electrolyte composition) are optimized with considerations of the multiple performance characteristics (surface roughness and passivation strength). The conducted experiments approve the effectiveness of the grey relational analysis.

JuchiHou (2010) used GRA technique for selecting a proper vendor to meet production demand. The selection process is based on their previous performance records, so the ranking determines the vendor for getting the supplier contract. The numeric score arrived for each characteristic is weighted by a factor, and then summing all scores together. As a result, achieving the highest grade would imply the best vendor candidate. This study utilized the Grey relational analysis to establish a complete and accurate evaluation model for selecting vendors.

The optimization of injection molding process parameters using the grey relational analysis method was studied by Chin-Ping Fung (2003). Nine experimental runs based on the Taguchi method of orthogonal arrays were performed to determine the best factor level condition. The wear volume losses of fiber-reinforced polybutylene terephthalate in different sliding
directions were selected to be the quality targets. The factor levels were assessed according to two chosen wear volume losses. The degree of influence that the controllable process factors exert on the wear volume losses was studied by investigating the correlation between them. By analyzing the grey relational grade matrix, the most influential process factor and the most easily influenced wear property was selected.

Huang, et al (2003) applied Grey relational analyses to determine the optimal selection of machining parameters for the Wire Electrical Discharge Machining (Wire-EDM) process. The Grey theory provided a solution for a system in which the model is unsure or the information is incomplete. GRA provided an efficient solution to the uncertainty, multi-input and discrete data problem. Based on Taguchi quality design concept, an L18 mixed-orthogonal array table was chosen for these experiments. With both Grey relational analysis and a statistical method, it is found that the table feed rate had a significant influence on the metal removal rate, whilst the gap width and surface roughness were mainly influenced by pulse-on time.

Based on analysis of uncertainty, ChihuiZhu et al (2007) presented grey system theory to handle the “grey” characteristic of IAQ. Grey comprehensive analysis of indoor air quality reveals that we should pay more attention to the air purification and humidity control in the design and maintenance of HVAC. In order to represent grey characteristic of IAQ system, the educed grey IAQ models can identify the variation intervals of key IAQ model parameters that are lack of directly measurable messages in practical situations. Furthermore, grey assessment is an effective multifactor comprehensive assessment method that can express the integrative influence of contamination indexes on indoor air quality.

The impact of air movement on perceived air quality (PAQ) and sick building syndrome (SBS) symptoms was studied by Melikov et al (2012).
In total, 124 human subjects participated in four series of experiments performed in climate chambers at different combinations of room air temperature (20, 23, 26 and 28 °C), relative humidity (30, 40 and 70%) and pollution level (low and high). Most of the experiments were performed with and without facially applied airflow at elevated velocity. The importance of the recirculated room air and clean, cool and dry outdoor air was studied.

The degree of improvement depended on the pollution level, the temperature and the humidity of the room air. At a low humidity level of 30% an increased velocity could compensate for the decrease in perceived air quality due to an elevated temperature ranging from 20 °C to 26 °C. In a room with 26 °C, increased air movement was also able to compensate for an increase in humidity from 30% to 60%, but not to 70%. The elevated velocity of recirculated polluted room air did not decrease the intensity of SBS symptoms, but movement of clean, cool and dry air did so. Energy-saving strategy of improving occupants’ comfort in rooms by moving room air at high velocity and maintaining room temperature high at reduced supply of outdoor air the pollution level may still cause negative health effects.

Grey relation analysis was used by Sue J Lin et al (2006) to analyze the productivity, aggregate energy consumption, and the use of fuel mix (electricity, coal, oil and gas) in relation to CO₂ emission changes. An innovative evaluative index system was devised to explore grey relation grades among economics, energy and environmental quality. Results indicate that a rapid increase in electricity generation during the past 10 years is the main reason for CO₂ emission increase in Taiwan.

The accuracies of different grey models such as Grey Model (1.1), Grey Verhulst model, modified grey models using Fourier series was investigated by Erdal Kayacan et al (2010). The researcher used highly noisy data, the United States dollar to Euro parity between the dates 01.01.2005 and
30.12.2007, were used to compare the performances of the different models. The simulation results showed that modified grey models have relatively higher performances on model fitting and forecasting. Among these grey models, the modified GM (1, 1) using Fourier series in time was found to be the best, in model fitting and forecasting.

The research article of Xianmin Wang et al (1999) discusses the difference between other uncertain theories such as stochastic and Grey system. A method based on Grey prediction model is proposed to predict building energy consumption. The proposed method was used for load calculation and verification purposes.

Chih-Hung Tsai et al (2003) utilized the Grey relational analysis in the Grey theory (Deng 1982) to establish a complete and accurate evaluation model for selecting vendors. This methodology significantly reduced the purchasing cost and increases the production efficiency and overall competitiveness.

Recent development in designing Airconditioning systems has indicated that the indoor comfort temperature strongly depends upon changes of the outdoor air temperature rather than to be a conventional fixed temperature set-point. The explanation is due to occupants' adaptability of thermal comfort to a dynamic environment in terms of their clothing and/or activities while the outdoor temperature can be explicitly used as an ultimate indicator of such changes to empirical function of the indoor comfort temperature. Thananchai Leephak preeda (2012) developed the first prototype embedded system to emulate an adaptive algorithm to numerically determine an indoor comfort temperature for a real-time control in an Airconditioning system.
An adaptive comfort model together with grey prediction model was presented by Thananchai Leephak preeda (2012) for exploring a practical application of a comfort temperature-based control for a single Airconditioned space, so as to show the viability of the proposed methodology by simulated results. The field studies by interview survey of satisfaction on thermal comfort within an Airconditioned reading room of a library confirmed the viability of the proposed real-time computerized implementation of adaptive indoor comfort temperature via the embedded system for a conventional Airconditioning unit in practical use.

### 2.7 NUMERICAL SIMULATION USING COMPUTATIONAL FLUID DYNAMICS

Han et al (1989) simulated passenger compartment cooling by Reynolds-averaged Navier-Stokes equations, together with the transport of energy equation, and solved in a time-dependent form. The effect of air density variation due to temperature was included as a buoyant force term in the analysis through a Boussinesq approximation. These transport equations were discretized, based on a finite volume method in a transformed domain. A general-body fitted curvilinear co-ordinate system was used to model interior geometries in the passenger compartment. The computational results for a car passenger compartment cooling showed overall flow information such as the propagation of cold air fronts, turbulent jet penetration and mixing, and buoyance-induced recirculating flows. Comparison of the available experimental data with predictions using isothermal wall boundary conditions showed excellent agreement in the prediction of the front breath-level temperature.

Posner et al (2003) compared the results from numerical simulations (CFD) with the experimented one-tenth sub-scaled model room using Laser doppler anemometry (LDA) and Particle image velocimetry.
(PIV) experimental measurements of indoor air flow. Laminar, k–ε turbulence, and RNG k–ε turbulence numerical models were used and evaluated with respect to their performance in simulating the flow in the model room, and results of the numerical simulations and velocimetry measurements show how obstructions can greatly influence the air flow and contaminant transport in a room. It is important, therefore, that obstructions be considered in ventilation design. Simulations predict the measured trends in a model room very well, with relative errors not much larger than 20%.

Air temperature and velocity are the two main factors affecting the thermal comfort indoors. These two values can be easily obtained using computational fluid dynamic (CFD) simulations together with the turbulence kinetic energy value. Mika Ruponen et al (2007) evaluated methods of calculating thermal comfort indices using CFD. Simulated results were compared against experimental data measured in a purpose build full-scale model room. The results showed that CFD data can reliably predict the thermal comfort values.

Kilic et al (2009) performed three-dimensional transient numerical analysis inside the automobile cabin during heating period. A three-dimensional vehicle cabin including glazing surfaces was modeled using the real dimensions of a car. A virtual manikin with real dimensions and physiological shape was added to the model of the vehicle cabin. It was assumed that the manikin surfaces were subjected to either constant heat flux or constant temperature. Three-dimensional fluid flow, temperature distribution, and heat transfer characteristics inside the cabin were calculated. Experimental measurements were compared with numerical results and discussed. The results of numerical calculations were reported to be good agreement with the experimental and theoretical data.
Ishihara et al (1991) used one-fourth scale three-dimensional model for numerical analysis to determine flow velocity distribution by measurements of visualized flow. The measurements of interior flow were obtained using a method which combined the particle-tracking technique, a basic method conventionally employed for flow visualization, with a pulsed-laser-light-sheet technique. Flow images taken with a video camera were then processed by means of an image processing system. Flow velocity distributions were obtained for two different discharge modes - a dashboard-vent mode in which air was discharged from four vents provided along the top of the dashboard, and a bi-level mode in which vents at the foot position were added to those of the first mode. Three-dimensional numerical analyses using a direct-simulation method were conducted to calculate the interior flow, and a comparison was made with the measured results obtained in the visualization experiment.

Wan et al (1991) used the air flow program PHOENICS to calculate the air flow and contaminant concentration in a passenger vehicle. Several positions of air supply and exhaust openings were examined and the velocity, temperature and concentration fields were compared. From these results the best solutions were selected to find the most comfortable indoor climate with respect to temperature and contaminant concentration.

Indexes of thermal comfort, such as PMV (Predicted Mean Vote), which have traditionally been applied to houses or buildings, are difficult to be applied to the automotive passenger compartment because of the large thermal differences that exist around vehicle occupants. Hagino et al (1992) in his research work analyzed the effects of temperature, airflow and solar radiation on passenger comfort in an Airconditioned vehicle. Based on the results obtained, a method was devised for predicting the feeling of comfort
passengers get from the thermal atmosphere in the vehicle interior. The necessity of providing a diffused airflow in an Airconditioned passenger compartment, based on the effects of airflow and comfort is also explained.

It is important to analyze the temperature and Air flow field inside the passenger compartment to improve the convenience and decrease energy consumption. Huajun Zhang et al (2009) used numerical simulation to study 3-D temperature distributions and flow field in a compartment with or without passengers. The results were validated by the experimental data and the numerical model was used to investigate the influence of different factors on the thermal comfort and the energy consumption. The test conditions and the numerical models were described in detail. The measured and predicted transient temperatures were compared and good agreement was obtained. The air temperature distribution in a steady test situation was also numerically predicted by both transient and steady model, and the agreements between the three sets of data showed the reliability of the models.

Personalized ventilation (PV) is aimed to improve the quality of inhaled air by delivering clean, humidified and temperature-controlled air directly to occupants’ breathing zone. Jiaqing Zhou et al (2012) investigated the effect of PV devices on the concentrations of volatile organic compounds (VOCs) emitted from carpet and the temperature around an occupant in an office. Numerical simulations were conducted using the computational fluid dynamics (CFD) for solving the continuity, momentum, energy, turbulence and concentration equations, and the simulation results were validated against the experimental data. Personal exposure effectiveness (PEE) and manikin-based equivalent temperature change were used as indices to evaluate the performance of the PV. The results showed that the existence of the PV device greatly influenced the temperature and VOCs distributions around the
occupant, but had little effect on those in the other parts of the office. The evaluation indices were found to increase with an increase of air flow rate. PV’s airflow rate had larger influence on Manikin-based equivalent temperature change than that on personalized exposure effectiveness. The ventilation strategies had a great influence on the two evaluation indices, and both of them decreased with an increase of ventilation rate.

The above research works created cognizance about the IAQ and its importance. The researchers have used various optimization techniques mainly to reduce the energy consumptions. All the above research works were carried in the airconditioned buildings like office and other working area.

I-Ping Chung et al (1998) used computational fluid dynamics (CFD) code to simulate the air currents and the contaminant decay inside a small scale model room with forced ventilation through a simple supply and return. The numerical results were validated with flow visualization experiments and local clearance rate measurements by laser extinction. The comparisons has shown excellent agreement on the inlet side of the room and fair agreement on the outlet side. The results shown that, for the room geometry studied, a ventilation system performs better when the inlet and the outlet are perpendicular to each other than when they are parallel to each other, and that partitions in the room can have a significant influence on ventilation performance.

Gao et al (2007) investigated the pollutant exposure reduction and thermal comfort that can be achieved with personalized ventilation (PV) design when a PV system is combined with two types of background airconditioning systems. Pollutants emitted from building materials were the target for the investigation of inhaled air quality, local discomfort associated with non-uniform thermal environment was focused for the investigation of
thermal comfort. These investigations were performed by combining CFD simulation of the 3D air flow and a multi-nodal human body thermo-regulation model. The results revealed some new characteristics of the three typical air distribution designs namely mixed ventilation, displacement ventilation and PV, and provide insight into the possible optimization of system combinations.

2.8 RESEARCH GAP IDENTIFICATION AND MOTIVATION

The research works listed in this chapter focused on applications of energy efficient techniques to attain human comfort and indoor air quality. Some of the prediction techniques like artificial neural network and fuzzy logic were used in previous studies to determine the minimum energy requirement to provide better indoor air quality for human comfort. Most of the research studies deal with the IAQ studies on office rooms, hotel rooms and class rooms. Optimization techniques like multi objective genetic algorithm, Grey relational algorithm and particle swarm optimization were used in the previous studies to get the optimal input conditions which provide energy efficient ventilation and optimum indoor air quality.

Large office buildings, schools and auditoriums use huge chilling units and air handling units, whereas cars have smaller volume compared to larger volume buildings, office and class rooms. The indoor pollutant concentration in cars is also more than in buildings. Car airconditioning requires not only thermal comfort but also healthy indoor conditions.

At present, cars have become an essential mode of personal transportation in human life. The present day cars are equipped with airconditioning systems for comfort of the passengers. The occupants inside the car always try to recirculate the conditioned air inside the cabin to achieve rapid cooling, thereby reducing the compressor load.
In general, the recirculation of conditioned air provides rapid cooling of cabin in passenger car. Due to occupants’ exhalation, the level of CO$_2$ increases inside the car cabin affecting the human comfort and health. When the level of CO$_2$ is more than 1200 ppm, it affects the human health adversely. Continues exposure to higher levels of CO$_2$ directly affects the oxygen carrying capacity of the red blood cells of human there by fatality can occur to the occupants in the car cabin.

In the light of the above, the current investigation is focused on the study of indoor air quality characteristics in an airconditioned car using prediction, optimization and numerical simulation methods. Experiments were conducted for different levels of IAQ control parameters in order to get better value of indoor air quality characteristics for human comfort and health.

The experimental setup, Design of experiments, assumptions, specifications of the IAQ probe and the procedure for conduct of experiments are detailed in the next Chapter.