IAQ Assessment for HVAC Performance in Selected Commercial and Office Buildings in India

M. Manzoor Hussain
Registrar of JNTU and Professor in Mechanical Engineering
Jawaharlal Nehru Technological University, Hyderabad, India
manzoorjntu@gmail.com

Raza Ahmed Khan
Research Scholar
Jawaharlal Nehru Architecture and Fine Arts University, Hyderabad, India
razahyd@gmail.com

Kavita Daryani Rao
Vice Chancellor and Professor in Architecture
Jawaharlal Nehru Architecture and Fine Arts University, Hyderabad, India
vc@jnafau.ac.in

Qutubuddin S.M.
Associate Professor
P.D.A. College of Engineering, Kalaburagi, India
syedqutub16@gmail.com

Abstract

This paper presents the results of a research questionnaire of building occupants in selected commercial and office buildings in Hyderabad. A total of 614 building occupants participated in the study from selected 28 commercial and office buildings. Many researchers have used questionnaire as an effective tool to measure the comfort of building occupants. Hence, teams were formed for conducting the questionnaire survey in different buildings. The occupants were explained the purpose of the study and asked to give their feedback on the form. The data was collected and analyzed to know their level of satisfaction with the building environment. Results show that the participants were mainly young males who spend a considerable time indoors. HVAC system is operational for most part of the year in those buildings. Some occupants have reported health issues like nasal irritation, headache, throat irritation, dry mouth, and drowsiness. These symptoms were related to their health history or seasonal effects besides air-conditioning issues. A majority of occupants have expressed their satisfaction with the building environments and all its environmental parameters. However, a small percentage of respondents have expressed dissatisfaction also which could be related to their individual backgrounds, medical issues, workloads, and attitudes. However, cigarette smoking remains an issue in commercial buildings.

Keywords
Indoor Air Quality, HVAC Systems, Commercial and Office Buildings, and building occupants.

1. Introduction
With the growth of economy in the late 1990s and early 2000s, many new commercial and office buildings were constructed in India that are completely air-tight and indoor environment is controlled by Heating, Ventilation, and Air-Conditioning (HVAC) systems. The air supplied in these buildings comes only through the HVAC system. Hence, there is a need to assess the quality of air inside these buildings, as people spend a lot of time indoors and their wellbeing depends on the Indoor Air Quality (IAQ).

Investigators throughout the world have recommended extensive occupant's questionnaire surveys for the assessment of IAQ. Some others have suggested formal medical examination, whereas some others have focused entirely upon the objective air quality data and the physical characteristics of the building (Collett, et al. 1993). Contemporary researchers involved in IAQ studies in commercial buildings have adopted a complementary ways of getting feedback from occupants in buildings (ASHRAE Handbook, 2017).

The survey questionnaires administered to building occupants are extensive in their degree of detail. They focus on lists of symptoms or a sign of discomfort, disease or ill health, individual's perceived attributes of the work environment, such as temperature, relative humidity, air movement, odour, and other data like period of stay in the building (Boje et al. 2020, Asif et al. 2020, Jin et al. 2020, Lei et al. 2019, Rafsanjani et al. 2020), type of air-conditioning system employed in the building, age and sex of the building occupants. (Vischer, 1993).

1.1 Objectives

The objective of this research study was to quantitatively and qualitatively assess the IAQ status in selected commercial and office buildings by taking the feedback from the building occupants. This includes workplace information, health and symptoms information, HVAC systems information and general information.

2. IAQ Assessment Questionnaire

About 50 commercial and office buildings were selected for this study in Indian city of Hyderabad, which is in the composite weather zone of the country. However, the research survey was conducted in twenty eight (28) commercial and office buildings based on the type of HVAC system employed (air cooled chillers, AHUs and VRF systems), the ease of accessibility and the size of the building. About six hundred and fourteen (614) building occupants participated in the survey and filled the research questionnaire.

A questionnaire was developed and administered for the building occupants with the aim of acquiring information on the following aspects:
(a) information like age, gender, profession, period of stay in the building, etc.
(b) signs or symptoms observed over a period of time such as headache, irritation, fatigue, skin rash or drowsiness
(c) health and medical history of the building occupants
(d) level of comfort with the work place environment with regard to temperature, relative humidity, air movement, smell, lighting and noise levels

The questionnaire was divided into different sections like the work place information, health and symptoms information, HVAC systems information and general information. The data gathered from this survey have been used to quantify the prevalence of any sick building syndrome (SBS) and comfort related complaints associated with the buildings.

3. Conducting the Survey

Teams were formed for conducting the questionnaire survey in different buildings and orientation was given to them regarding the HVAC system and issues related to air quality. The survey teams visited the selected buildings by acquiring the prior permission from building owners or their representatives. The occupants of these buildings were introduced to the objectives of the study and its importance for the work environment. Their concerns were personally responded to and they were ensured that their identity will be kept in confidence. The researcher explained the academic nature of the research and that the data will be used solely for the stated purpose. Apart from this, it was communicated to them that the study would come up with recommendations to improve their working environment, and they were encouraged to participate in the study by filling in the questionnaires.

Many building occupants showed interest in the survey, appreciated the objectives of the study and willingly participated to register their feedback by filling in the questionnaire. The investigating team preferred to get the questionnaires filled on the spot so that if the occupants have any doubts it can be discussed and clarified immediately. However, in some buildings, the questionnaires were distributed to occupants and collected on the following day as per the convenience of respondents and their management.

4. Result Analysis

The response analysis of questionnaires collected from the building occupants is discussed in the following paragraphs. The questionnaire has been designed into four divisions that include work place information, health and symptoms information, HVAC systems information, and general information about occupants. The office buildings have been classified as large and medium buildings based on the size and ownership of the building. Usually large Multi-National Companies (MNCs) have their own buildings as its corporate office building, which have been referred to as large office buildings. There are other office buildings which work in rented or leased premises in a medium sized building, which are referred to as medium office buildings. In some medium sized buildings, there are more than one offices working on different floors. However, commercial buildings have not been classified as old and new because of their small number. Most of these office and commercial buildings are newly constructed in the early 2000's.

This section deals with the summary of results of the occupant's questionnaire in commercial, large and medium office buildings. A total of 614 questionnaires were filled in by the occupants of 28 buildings in Hyderabad.

4.1 Work Place Information

The surveyed building occupants were asked regarding the time duration they spend in those buildings. The longer they stay, the more reliable is their feedback as they can comment on what they have experienced in that space. About 61 percent of the surveyed occupants spend more than eight hours in their working environments, and about 30 percent spend between 6 to 8 hours as shown in Figure 1. About 7 percent of respondents spend about 4 to 6 hours in those buildings, and only about 2% spend less than 4 hours.

More than 66 percent of the surveyed occupants indicated that they were working in those buildings for more than a year. Another 16 percent indicated of occupying those working spaces somewhere between 6 to 12 months. This information gives credibility to the collected data as these occupants spend a reasonable amount of time inside the spaces under investigation for quite a long time (Figure 1).

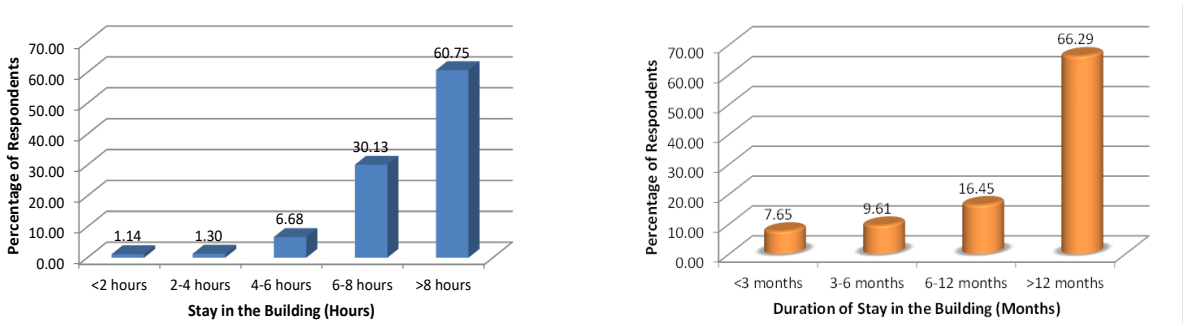

Figure 1. Number of hours spent per day and duration of stay in the selected buildings

The surveyed occupants were requested to describe the comfort conditions of their working environment. 86 percent of respondents reported that the space is comfortable as shown in Figure 2. However, 12 percent were uncomfortable with their indoor environment. The reasons for this dissatisfaction could be the complaints related to HVAC systems and the lack of maintenance in some buildings (Figure 2-5).

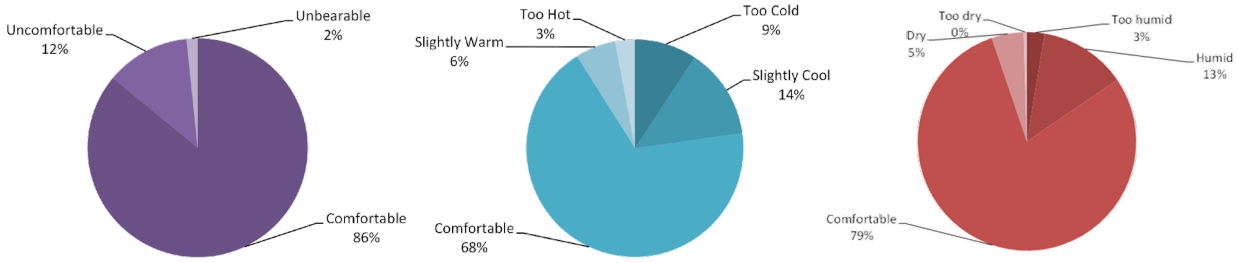

Figure 2. Perception of overall comfort, thermal comfort, relative humidity in surveyed buildings

The occupants were inquired for their levels of comfort or discomfort with the environmental parameters. These parameters include the temperature, relative humidity, noise level, lighting level, and air movement. These are the indicators of the general comfort conditions in any building. About 88 percent of the total surveyed occupants perceive the environment as thermally comfortable, including the slightly cool and warm conditions as shown in Figure 2. Only cold and hot conditions have been considered as thermally uncomfortable that was perceived by about 12 percent respondents.

With regard to relative humidity, about 79 percent of respondents perceive it as comfortable and the rest either feels humid or dry in different spaces as shown in Figure 2.

Regarding the acoustical performance of buildings, almost 76 percent of surveyed occupants perceive the environment as quite as shown in Figure 3. About 22 percent feel it as moderately noisy and only 2 percent opine it to be too noisy.

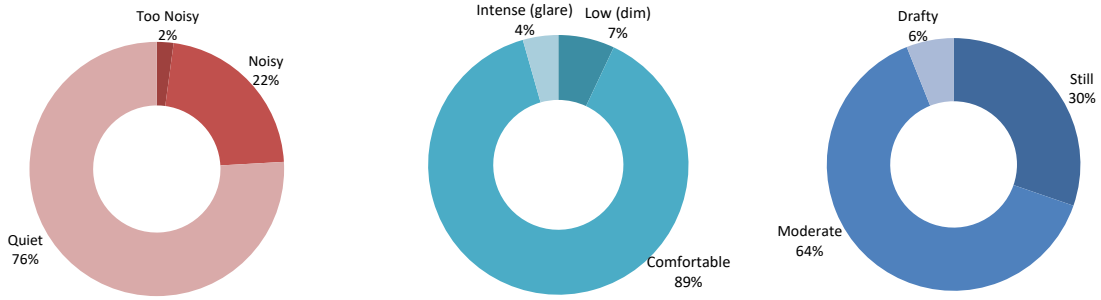

Figure 3. Perception of noise levels, lighting levels, air movement in surveyed buildings

Almost 89 percent of occupants are comfortable with lighting levels in their workspaces as shown in Figure 3. Only about 7 percent complained regarding dim lighting and 4 percent about glare. Lighting is an important criteria for wellbeing of building occupants as reported by many researchers (Edwards and Torcellini, 2002).

89 percent of the occupants perceive the air to be clean, and almost 94 percent feel the movement as either still or moderate. Only about 6 percent of the occupants have complained about the draft conditions. Hence a majority of the occupants are satisfied with the environmental conditions in their indoor spaces to a larger extent. A minor percentage of dissatisfaction cannot be ruled out in any space, which depends on a number of factors like their background, medical history, workloads, and attitude. It is almost impossible to design a space that provides comfort and satisfaction to all the occupants.

With regard to the presence of odour in the work environment, about 67 percent of respondents did not notice any odour as shown in Figure 4. 27 percent concede that it is present in slight magnitude; whereas another 3 percent perceive it as moderate and only 3 percent feel it as strong odour. The possible causes for the presence of odour in all the three types of buildings are cigarette smoking (about 35 percent), toilet or sewage gas (12 percent), car exhaust, carpets, furniture and other reasons like building materials, musty smell, and chemicals. The main cause of odour in spaces has been identified as cigarette smoking in all the types of investigated buildings.

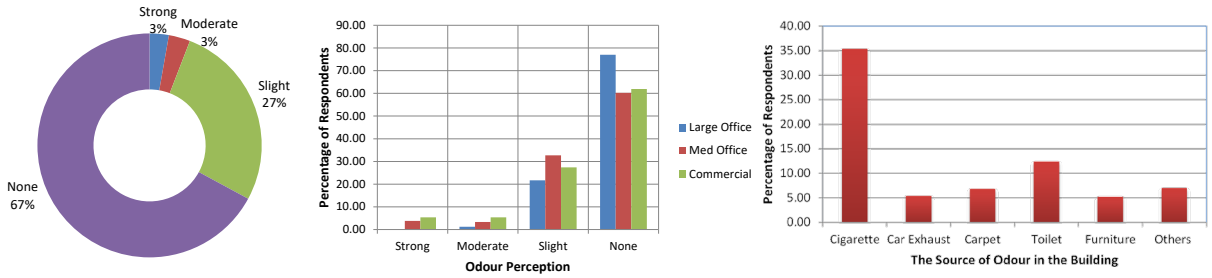

Figure 4. Perception of odour in different building types and their possible sources

About 35 percent of the surveyed occupants have reported that people smoke inside their buildings as shown in Figure 4. However, 25 percent respondents are cigarette smokers who are not bothered if others too smoke in their work environments. This problem is much severe in case of commercial buildings that recorded the highest percentage of tobacco smokers inside buildings. Even if a few among these smokers smoke inside the building, it is sufficient to create harmful contaminants, which take hour to dilute and settle down. 54 percent of surveyed occupants have also indicated that they need to clean their office furniture for dust accumulation with frequencies of at least once per day. Commercial buildings are the worst effected with the problem of dust accumulation.

4.2 Health and Symptoms Information

A variety of health related symptoms are related to poor IAQ, that includes eye irritation, nose irritation, throat irritation, headaches, coughs, asthma, allergic reactions, lethargy, breathing problems, nausea, and dizziness. The major problems that have been reported by the respondents are the nasal irritation and headache, with about 19 percent and 17 percent suffering from it respectively as shown in Figure 5. Throat irritation has been reported by 16 percent respondents, dry mouth has been reported by 15 percent surveyed occupants, and drowsiness been reported by 14 percent surveyed population. Other noticeable problems include fatigue and eye irritation. More or less these symptoms are similar in all the three types of buildings that have been investigated.

About 37 percent of the respondents who reported for various symptoms gave the feedback that these symptoms disappear once they leave their work place environment. However, 25 percent do not agree with them and indicated that the symptoms continue even after they leave those buildings. The reasons for these conditions may include their health conditions, attitude towards work, working conditions, workplace environment, and the weather conditions. Only about 6 percent of the respondents reported to have observe these symptoms on a daily basis, 18 percent observe them twice a week, and about 16 percent observe them once a week as shown in Figure 5. These figures clarify the picture that only a small percentage of occupants are dissatisfied most of the time.

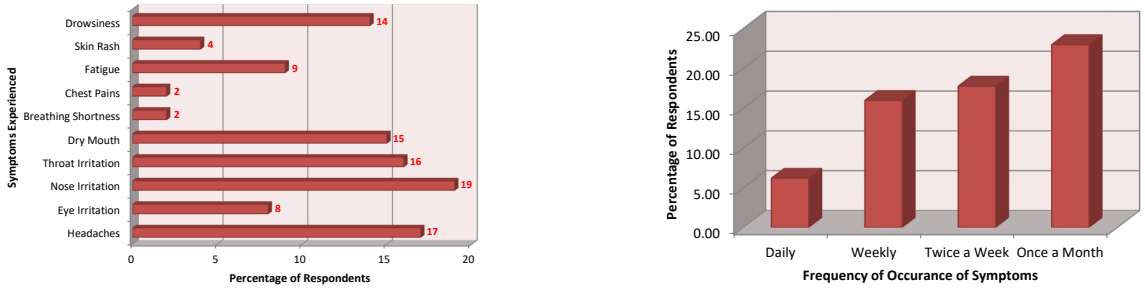

Figure 5. Health symptoms experienced by occupants and frequency of occurrence of symptoms

The frequency of occurrence of these symptoms in medium office buildings is higher than in large office buildings and commercial buildings. The reasons could be the level of interaction with various people, contaminant generation due to varied activity, and the presence of smoke and dust. Most of the complaints have been reported during summer and evenings, which again implies that these symptoms have a seasonal impact. These are the moments when the cooling load is at its peak.

To know if they were suffering from any illness that could have an impact on the outcome of the survey results, the occupants were asked to provide their medical history. About 25 percent suffer from various allergies, 7 percent from migraines, and 5 percent from asthma. About 13 percent suffer from some other health issues.

4.3 HVAC System Information

Information related to the HVAC systems, its maintenance practices, and health related issues associated with these systems, were sought from the occupants of investigated buildings. 15 percent of the respondents reported that the systems are operational throughout the year, and 54 percent reported that it works for about 9 months as shown in

Figure 6. This may be due to the weather conditions of Hyderabad, India, which is usually hot and warm for about 6 to 8 months and the remaining part of the year is pleasant.

About 8 percent of the surveyed occupants have complained that these systems provide either too hot or cold air to the spaces. Reasons for this complaint include direct throw of air from the supply diffuser, or position near the return grilles, or poor distribution of air. Almost 53 percent of the occupants have indicated that the maintenance of these systems is carried out once a year in their buildings while 18 percent reported that it is done once in two years as shown in Figure 6. However, some occupants were found to be ignorant on this issue (Figure 6).

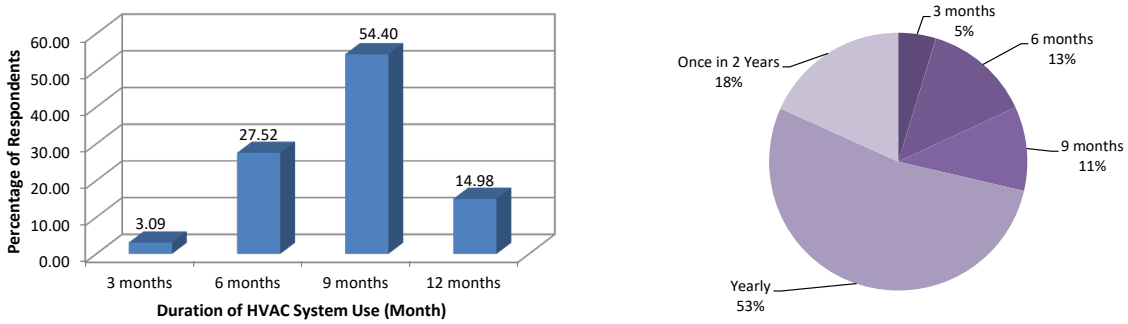

Figure 6. Usage of HVAC systems and frequency of HVAC maintenance in surveyed buildings

4.4 General Information

About 72 percent of the respondents were young males and 66 percent of surveyed occupants were less than 40 years of age. It is important to mention here about their age and sex as these factors have an influence on the perception of comfort conditions (Collett, 1993). Almost 91 percent of the respondents spend more than 6 hours inside the investigated buildings. Since they spend considerable time inside buildings, it gives credibility to the collected data as a true picture of indoor conditions.

5. Conclusion

Research questionnaire of building occupants is an effective tool for getting the feedback about the perception of spaces in which people spend a considerable time. A total of 614 building occupants participated in the study from 28 commercial and office buildings. 72% of these respondents were males and 28% females, 66% were below 40 years of age. 91% of these occupants spend more than 6 hours inside buildings.

15% respondents reported that the HVAC systems are operational throughout the year, while 54% reported it to be functional for about 9 months a year. 53% reported that annual maintenance is carried out for HVAC.

When asked about the health related issues, 19% reported nasal irritation, 17% headache, 16% throat irritation, 15% dry mouth, and 14% drowsiness. Most of the complaints have been reported during evening time and summer periods which implies that the symptoms may be related to season. 25% respondents have a history of various allergies.

About 86% occupants have expressed their comfort with the indoor environment space. In response to their comfort levels with the environmental parameters, 88% are thermally comfortable, 79% are comfortable with the humidity levels, 76% are acoustically comfortable, 89% are comfortable with lighting levels, 89% perceive the air to be clean, almost 94% feel the movement as either still or moderate, and 67%of respondents did not notice any odour.

Hence, the majority of the building occupants were observed to be satisfied with the environmental conditions in their indoor spaces to a larger extent. A small percentage of dissatisfaction cannot be ruled out in any building, which depends on a number of factors like the background of respondents, medical history, workloads, and attitude. 35% respondents indicated that some people smoke in the surroundings and there are no separate smoking zones. This problem is of concern in commercial buildings rather than office buildings.

References

ASHRAE Handbook. *Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, Georgia, 2017

Asif, A.; Zeeshan, M. Indoor temperature, relative humidity and CO2 monitoring and air exchange rates simulation utilizing system dynamics tools for naturally ventilated classrooms. Build. Environ., vol. 180, pp. 106-110. 2020

Boje, C.; Guerriero, A.; Kubicki, S.; Rezgui, Y. Towards a semantic Construction Digital Twin: Directions for future research. *Autom. Constr.* Vol. 114, e- 103179, 2020.

Collett, C.W., Ross, J.A., and Sterling, E.M. Strategies for the Investigation of indoor Air Quality Problems and Findings fro their Implementation. *ASHRAE Transactions*, Vol.99, Part 2, pp. 1104-1110, 1993.

Edwards, L. and Torcellini, P. Technical Report: A Literature Review of the Effects of Natural Light on Building Occupants, NREL/TP-550-30769, *National Renewable Energy Laboratory*, Colorado, 2002.

EPA-402-K-97-003. An Office Building Occupant's Guide to Indoor Air Quality. *U.S. Environmental Protection Agency (EPA), and Office of Air and Radiation*, October, 1997.

Jin, R.; Zhang, H.; Liu, D.; Yan, X. IoT-based detecting, locating and alarming of unauthorized intrusion on construction sites. Autom. Constr., vol. 118, 1pp. 03278. 2020

Lei, L.; Chen, W.; Xue, Y.; Liu, W. A comprehensive evaluation method for indoor air quality of buildings based on rough sets and a wavelet neural network. *Build. Environ,* vol. 162, 2019.

Rafsanjani, H.N.; Ghahramani, A. Towards utilizing internet of things (IoT) devices for understanding individual occupants0 energy usage of personal and shared appliances in office buildings. *J. Build. Eng.*, vol. 27, e-100948, 2020

Vischer, J.C. Using Occupant's Experiences to Monitor Indoor Air Quality in Office Buildings. *ASHRAE Transactions*, Vol. 99, Part 21, pp. 1111-1115, 1993.

Acknowledgements

Acknowledgements are due to Jawaharlal Nehru Architecture and Fine Arts University (JNAFAU) Hyderabad and Nawab Shah Alam Khan College of Engineering and Technology (NSAKCET) Hyderabad for facilitating this research work. The authors wish to thank the team members who helped in conducting the questionnaire survey, all the building occupants for participating in the study, and all building owners for allowing this study in their premises.

Biographies

Dr. M. Manzoor Hussain is presently Registrar of Jawaharlal Nehru Technological University, Hyderabad and Professor in Mechanical Engineering Department. Earlier he has served as Director of Admissions for three years, and the founder Principal of constituent college of JNTUH at Sultanpur, Sangareddy District. He was the chairman of Board of Studies of JNTU in Mechatronics Engineering and Automobile Engineering. He has guided over 50 post graduate thesis and supervised 21 PhD scholars and currently 7 research scholars are working under his supervision. His areas of research include composite materials, manufacturing, additive manufacturing, air-conditioning, welding and industrial engineering. He has over 26 years of experience in teaching and administration in various capacities. He has published over 65 papers in peer reviewed journals and National and International conferences. He was awarded the best teacher award by Telangana State Government in the year 2016.

Raza Ahmed Khan is a Research Scholar, pursuing his Ph.D from Jawaharlal Nehru Architecture and Fine Arts University, Hyderabad. He did his Bachelor's in Mechanical Engineering from Osmania University, Hyderabad and Masters' in Architectural Engineering from King Fahd University of Petroleum and Minerals, Dhahran. He has more than 20 years' experience in teaching, research and industry. He has published more than 15 papers in International and National journals and Conferences. He has designed the course Heating, Ventilation and Air-Conditioning (HVAC) for the post-graduate curriculum in Mechanical Engineering, Osmania University. He is a fellow of the Institute of Engineers (India), and member of professional societies such as ISHRAE, ISTE, and IAENG. He has established ISHRAE Students Chapter at NSAK College of Engineering and Technology. Research interests include HVAC Systems, Indoor Air Quality, Energy Conservation, Renewable Energy Resources, and Electro Mobility.

Dr. Kavita Daryani Rao has studied Architecture and specialized in Housing. She is presently the Vice-Chancellor of Jawaharlal Nehru Architecture and Fine Arts University, Hyderabad and has been involved in academic administration in various capacities. As Director of Evaluation, she introduced many measures in the examination

section of the University for Automation. She is keenly interested in teaching-learning methodology. She is also interested in collaborative work with other institutions and has been instrumental in collaborating with international universities. She had initiated an Incubation Centre in the University which is currently working on rainwater harvesting and affordable art initiatives. She received the IIID (HRC) Lifetime Achievement Award in 2013 and the Telangana State Government Award on International Women's Day in 2018 to recognize her contribution to academics. She has been nominated as a Member of Council of Architecture by the Government of Telangana.

Dr. Qutubuddin S.M. is presently working as Associate Professor, Industrial and Production Engineering Department, P.D.A. College of Engineering, Gulbarga. He has more than 28 years experience in teaching and research and has published more than 35 papers in International and National journals and Conferences. He has introduced the course Human Factors and Ergonomics in the curriculum in under graduate engineering and has developed laboratories such as Industrial Engineering Laboratory and Ergonomics Laboratory. He is a life member of professional societies such as ISTE, IIPE, IAENG, and ISE. He is a regular member of various committees' of IEOM Society conferences. He has established a IEOM Society student Chapter at PDA College of Engineering. Research interest include Industrial Ergonomics; Human Factors; Occupational Health and Safety; Productivity Improvement Studies; Production/Operations Management; Environmental Ergonomics.