Terminal 2 of Mumbai Airport is a benchmark for indoor environmental quality

ISHRAE Position Paper on Indoor Environmental Quality

By IEQ Committee of ISHRAE

This Position Paper is being published in the *Journal* for wide circulation among ISHRAE members. Based on the comments received, the Committee will review the Paper – ***Technical Editor***

Foreword

Dear Friends,

India is currently ranked amongst the fastest growing economies in the world, which is leading to a construction boom in the cities. While the leadership of the country is working on an ambitious task of creating 100 Smart Cities, simultaneously, there is a need to ensure a healthy and safe environment for the inhabitants. With most major Indian cities scoring poorly on ambient air quality, ISHRAE has decided to undertake the task of spreading awareness on the need for good Indoor Environment Quality (IEQ), which will focus on areas like thermal comfort, indoor air quality, lighting quality (both artificial and day-lighting), noise and vibration and other areas that affect occupant health inside the buildings.

As this topic is relatively new to the country, ISHRAE under the leadership of National President K. Ramachandran has undertaken the task of generating awareness in the industry. Therefore, a Committee comprising the following experts has been constituted and tasked with bringing out a Standard on IEQ:

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2. Dr. Jyotirmay Mathur
3. Maija Virta
4. Gautham Baliga
5. Leena Thomas
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7. Shankar Rajasekaran
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11. Rahul Aeron
12. Nitin M. Deodhar
13. Prof. M. Ramgopal
14. Ashwini Mehra (ISHRAE Executive Secretary)

As a first step, the Committee has brainstormed to prepare a paper on the subject, which outlines the position of the Society on this important aspect. The Committee is now studying the work done by other countries/societies including ASHRAE and thereafter commence work on the Standard to include subjects that are relevant to our country. The ISHRAE IEQ Standard is expected to be ready by early next year, and we plan to offer it to IGBC and TERI to integrate it with their Green building rating systems. We also intend to offer this document to the Government of India through BIS for possible adoption as a National Standard in future.

I am sure you will enjoy reading the position paper of ISHRAE and feel free to reach out to Committee members for any inputs on the subject.

Yours in ISHRAE,

Ashish Rakheja

National Chair: Standards

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Introduction

Indoor Environmental Quality (IEQ) has an impact on the health of the people and therefore, improves comfort, safety, health and productivity. IEQ refers to the quality of a building's indoor environment and is determined by many factors, including indoor air quality, thermal comfort, lighting quality, acoustic conditions as well as furniture and space layout.

In a good indoor environment, work efficiency of occupants gets enhanced, learning results are better among students and absenteeism is lower. This, in turn, increases workplace productivity and test-scores in schools; this is supported by research.

Research has shown that the pollutants in indoor air have a clear link with productivity, sense of wellbeing and occupant health and in the long term lead to health hazards like asthma, allergies, headaches and respiratory diseases. Furthermore, temperatures that are too high or too low, continuous high noise levels, or excessively bright or inadequate lighting levels increase the stress levels in the human body, thus creating health issues like sleep disorder, digestive problems, memory and concentration impairment.

ISHRAE is committed to increase awareness about the importance of IEQ and its impacts on human health. Emphasis on IEQ in building design and operations need not detract from energy savings in buildings. ISHRAE emphasizes the fact that design and operation of HVAC systems in buildings can significantly impact occupants' exposure to air pollution, thermal discomfort, visual discomfort and acoustic problems.

Respiratory Ailments: Over 2 Cr Death

NEW DELHI: The government on Thursday said that over two crore people have died across the country due to respiratory ailments, generally caused by air pollution, in past nine years. In a written reply in the Rajya Sabha, environment minister Prakash Javadekar said 2,61,52,957 people have died due to Acute Respiratory Infection during the 2006-15 period. "Air pollution is known to be one of the aggravating factors for many respiratory ailments..." – PTI

(Source: The Economic Times, Mumbai, August 7, 2015)

Indoor Air Quality

Indoor Air Quality (IAQ) is healthy when the air does not contain contaminants in harmful concentrations, and is acceptable when the majority of people feel satisfied. Exposure to hazardous airborne agents present in many indoor spaces causes adverse effects such as respiratory and cardiovascular diseases, allergy and irritation of the respiratory tract and possibly leads to cancer[1]. That is why our responsibility is to provide healthy indoor environment for occupants[2]. We breathe about 12,000 litres of air every day and it is vital for our health to make sure that the air we breathe is clean.

Indoor air pollution is the second highest killer in India and is linked to outdoor air quality. Outdoor air pollution has a direct impact on indoor air quality. The cost of air pollution to the society in 2010 was estimated at US$0.5 trillion in India, according to a recent study by the Organization for Economic Co-Operation and Development (OECD)[3]. Due to poor outdoor air quality in most cities in India, IAQ cannot be improved merely by increasing the ventilation rate without proper ambient air particulate and gas filtration, as prescribed in several international standards[4-6].

Respirable Suspended Particulate Matter (RSPM) is one of the main ambient air pollutants. According to the database of Central Pollution Control Board (CPCB), Government of India[7], which includes RSPM levels of 124 Indian cities, 123 cities have $PM_{2.5}$ annual average level above WHO Air Quality Guideline level (10 µg/m^3)[8]. The International Agency for Research on Cancer (IARC) concluded in 2013 that ultra-fine particulate matter is carcinogenic to humans. If no action is taken to bring down the current RSPM levels, deaths from air pollution would increase by 20% to 30% in India[9].

The main sources of particulate matter in India are; vehicle emissions, household cooking (especially cooking with biomass and frying), thermal power plants, biomass burning, construction work, unattended debris, fossil fuel (such as diesel) based power generators and various industrial processes.

In addition to RSPM, there are a host of other pollutants that contribute towards deterioration of the ambient air quality. In many areas, Ozone (O_3), Sulphur dioxide (SO_2), Oxides of Nitrogen (NO_x), Hydrogen Sulphide (H_2S) and Lead (Pb) levels are also reported to be significantly higher as compared to international guidelines.

Carbon dioxide (CO_2) is neither an indoor air pollutant by itself nor a direct health risk in typical indoor concentrations (500-1200 ppm). However, high levels of CO_2 may lead to drowsiness, headache or lower activity levels among occupants, and thus should be controlled. Since measuring CO_2 level is relatively easy as compared to other pollutants, it is used as an indicator of ventilation efficiency.

Solvents, paints and other building materials as well as cleaning agents may release Volatile Organic Compounds (VOCs) into the indoor air. Emissions are typically high in newly finished interiors, and reduce exponentially over time.

ISHRAE holds the view that most common IAQ problems are caused by inadequate ventilation and filtration, and improper air distribution. Correct design, material selection and proper

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maintenance of equipment can enhance IAQ. Undoubtedly, the HVAC industry is in a key position to improve the IAQ and positively impact human health in buildings.

Thermal Comfort

Thermal conditions within living and working environments play a critical role in influencing occupant comfort and wellbeing. Research has shown that along with air quality, thermal comfort is one of the critical variables influencing worker productivity[10]. In addition, a substantial part of operational energy in contemporary buildings is used to alleviate thermal discomfort. In India, cooling energy comprises 40-60% of the total energy used in air-conditioned buildings.

Predicted Mean Vote (PMV) model expressed as a function of air temperature, mean radiant temperature, air velocity, humidity, metabolic activity and clothing is widely used to predict thermal comfort in air-conditioned buildings. While the PMV model remains the basis for Western and European standards of thermal comfort[6, 11], these standards also refer to the adaptive thermal comfort model to predict acceptable indoor thermal conditions.

The adaptive thermal comfort theory suggests that indoor comfort is influenced by outdoor climate, and aspects such as connection to the outdoors and control over the immediate environment allow occupants to adapt to a wider range of thermal conditions.

In the absence of a thermal comfort model specific to Indian conditions, the current practice is to adopt ASHRAE guidelines for air-conditioned building. However, a number of field studies in India suggest that the adaptive thermal comfort model could be a more relevant approach.

Central Building Research Institute (CBRI) in India has formulated an India-specific thermal comfort assessment criteria termed as the Tropical Summer Index (TSI). Researchers have conducted thermal comfort surveys on a wide range of occupants in different types of buildings.

Following are the major findings of these studies:

- Indian building occupants are more adaptive and tolerant of higher temperatures during summer conditions than predicted under the PMV model.
- Indians are found to be comfortable over a larger range of air velocity[12].
- In addition to temperature and air velocity, high tolerance for humidity is also found, especially in warm and humid climatic zones[13].

Adaptive models for thermal comfort for naturally ventilated and mixed mode commercial buildings that cover the five climate zones in India show Indian occupants to be more adaptive than would be predicted under the adaptive models derived from ASHRAE-55-2013 and EN 15251:2007[14].

There is up to 15% energy saving potential in buildings with the use of adaptive approach in operation of air-conditioning systems by keeping a floating thermostat set point in place of a fixed set point[15, 16].

ISHRAE emphasizes that thermal comfort can be governed through various combinations of air velocity, humidity, air temperature, mean radiant temperature and clothing adjustment. ISHRAE further suggests that metrics such as 'Effective Temperature' and 'Operative Temperature', which consider combined effect of the above parameters, should be adopted as the basis for thermal comfort evaluation, rather than air temperature alone.

Humidity and Mould

Humidity in occupied spaces affects the comfort of the occupants, corrosion of the building materials, electrostatic discharge, mould and mildew, bacteria and virus. Although human beings can tolerate a wide range of humidity conditions without the feeling of discomfort, very low humidity conditions cause dryness of the skin and mucous membranes in the nose, throat and eyes, while extreme humidity results in sweating and discomfort, particularly at higher temperatures.

Moisture is the universal requirement for fungal growth; keeping it under control is critical to inhibit mildew and mould. Mildew grows on damp organic materials such as paper. Moulds can damage property and can spoil food. Certain moulds can be very pathogenic and cause disease. The health consequences are particularly significant in hospitals, but can impact users in all types of buildings.

Building construction materials used in India are usually not airtight. Hence, use of proper vapor barriers on exterior walls can alleviate the condensation problem. Some HVAC components cause suction leading to negative pressure in the building. At such places, if the space interfaces with the exterior wall, humid outside air gets in through cracks.

The condensate drain pans of air handling units, filters, duct work downstream of the cooling coil, and drain from indoor units are some places where fungal growth is commonly found. Limiting the drift of condensate water, restricting the relative humidity in the ductwork and the use of well-maintained filters can limit the growth of moulds in the duct work.

ISHRAE considers that the problem of humidity driven mould is a serious health risk in buildings. This problem has a greater significance in air-conditioned buildings as compared to naturally ventilated buildings.

Lighting Conditions

Good lighting provides adequate level of task visibility without causing discomfort, and creates an attractive and interesting visual environment while achieving energy efficiency, providing positive

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impact on health, productivity and wellbeing of occupants. Research shows that light has significant impact on many bodily functions, including the nervous system, circadian rhythms, pituitary gland, endocrine system, pineal gland and alertness, which are affected by different wavelengths of light.[9,17,18]

In a hospital environment, it is found that patients exposed to an increased intensity of sunlight experienced less perceived stress, marginally less pain, took 22% less analgesic medication per hour, and had 21% less pain medication costs [19-20].

Increased lighting can be beneficial to elderly people with deteriorating vision. An environment that is easy and comfortable helps to promote an elderly person's sense of competence and independence, increases safety, promotes better health and adds to quality of life. Low lighting levels may lead to tripping and falling due to lower visibility of hazards such as unexpected steps or sudden changes in floor surfaces, etc.

Daylighting has been associated with higher productivity, lower absenteeism, fewer errors or defects in products, positive attitudes, reduced fatigue, and reduced eyestrain. One of the important psychological aspects from daylighting is the connection with the outdoor environment. The spectral requirements of the circadian system are also more closely matched by daylight than by most artificial light sources. Tapping daylight will not only reduce the need for artificial lighting but also reduce cooling load. However, heat gain and glare related issues need to be addressed with use of control strategies.

ISHRAE opines that an integrated design for daylight and artificial lighting should include orientation, form of the building, window sizes and placement, selection of glass type, shading devices, skylight design, interior furniture layout, construction materials and finishes. Standards need to ensure that they avoid issues such as glare on vertical planes as well. One of the major shifts observed in work spaces is a shift from horizontal work planes (desks and paper focus) to vertical work planes (computer screens). Standards also need to ensure that they avoid glare on vertical planes, and related issues as well.

Acoustic Environment

Noise is considered as unwanted sound. Noise can affect productivity and health in commercial and residential buildings. Loud noise can cause hearing loss, stress, alter sleep patterns, and affect heart rate based on other IEQ co-factors. However, sound need not be loud to become unwanted and annoying.

Noise can mask important sounds and disrupt communication between individuals in a variety of settings. Noise can disrupt face-to-face and telephone conversation, and the enjoyment of radio and television. Interference with communication has proved to be one of the most important components of noise-related annoyance. It can cause fatigue and vocal strain in those who need to communicate in spite of the noise.

Night noise management is especially important in residential buildings, hospitals and hotels located near main roads. According to research, 40 dB is equivalent to the Lowest-Observed-Adverse-Effect Level (LOAEL) for night noise. Above 55 dB, cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise[21].

Noise is also a major problem in open plan offices and call centers. Speech is the most disturbing noise that prevents people from concentrating on their work. Studies have shown that speech impairs the performance of cognitively demanding tasks, e.g. verbal and memory recall tasks. A good background noise level in open plan office is 40dB, which is usually generated by ventilation systems; active background noise generation may also be used, if required.

ISHRAE holds the view that noise level and acoustic privacy should be controlled by acoustical means, i.e. by incorporating acoustic considerations in building design, adding sufficient amount of sound absorption material to the space and making sure that the background noise level is appropriate.

Evaluating IEQ – Measurement and Occupant Feedback

Traditionally, the evaluation of the indoor environmental quality of buildings has focussed on measurement of the physical attributes of the environment. The attributes can be assessed via

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site measurements taken over the course of one day or on the basis of long term monitoring from BMS systems or data loggers, using approved measurement protocols and instrumentation with the required resolution and accuracy. This approach is used to verify whether the physical attributes satisfy stipulated targets.

It should be recognised that physical measurements taken in isolation do not provide the full picture of occupant experience. While the measurement of physical attributes yields quantitative data, it can restrict the focus to easily measurable parameters, often ignoring combined effects of multiple variables affecting thermal, visual and acoustic comfort. Aspects such as acoustic privacy and local effects of comfort (drafts, temperature variation, stuffiness, glare and odours) are also difficult to measure and do not get picked up without direct feedback from occupants.

Researchers have demonstrated the importance of understanding users' experience as a measure of the effectiveness of the indoor environment [22, 23]. Qualitative survey instruments such as Building Use Studies, CBE Occupant Indoor Environmental Quality (IEQ) Survey and BOSSA are carefully designed to capture occupant feedback and satisfaction regarding building design, overall comfort, thermal comfort and air quality, lighting, noise, privacy, space usage, design, perceived health and productivity by 'asking the occupant'[24, 25]. The survey feedback is used for diagnostic purposes as well as for benchmarking buildings in relation to one another as seen in post occupancy evaluation (POE) studies of individual and large sets of buildings[26, 27]. Following an increased recognition of the value of this approach, these POE survey tools are now included in rating IEQ in tools such as LEED, WELL and NABERS Indoor Environmental Rating Tool.

Energy and IEQ

ISHRAE emphasizes that IEQ considerations need not be a constraint for energy efficiency in buildings. An integrated design approach that considers both indoor environmental quality and energy is crucial for the long term sustainability of buildings in India. Post occupancy evaluations of successful green buildings indicate they can deliver low energy as well as high indoor environmental quality and comfort for its occupants. Typically, such buildings harness low-energy attributes that people like such as natural light, fresh air, connection with outdoor and an adaptive approach to thermal comfort, coupled with low VOC finishes and a user responsive approach to their operation and management.

ISHRAE recognises that 80% of the electricity produced in India comes from fossil fuel-based thermal power plants and any additional energy consumption will result in increase in greenhouse gas emissions. However, poorly conceived strategies for energy efficiency can create detrimental effects for IEQ. A case in point is the Sick Building Syndrome that arose as a consequence of reduced outdoor air ventilation rates in European buildings in the late 1970s and 80s following the oil crisis. On the other hand, in some extreme cases (such as extreme outdoor air pollution), where additional energy consumption cannot be avoided for meeting IEQ requirements, a balanced approach between incremental energy consumption and increased pollution load should be adopted.

ISHRAE's Position

- Air pollution is one of the biggest environmental health risks in India and needs to be addressed by all stakeholders i.e. people, government and industry. Outdoor and indoor air quality need to be improved urgently. As indoor air quality improvements are easier to implement, the focus should be on making buildings healthier for its users.
- Controlling contaminants at source is the most important activity for improving air quality. Purification of outdoor air before being supplied into the building is important, along with material and equipment selection.
- Good construction and installation practices, low emission operation and maintenance practices are required in order to improve IAQ.
- Where outdoor air quality does not meet National AQI, emphasis should be given to ventilation and filtration design.
- An Adaptive Thermal Comfort approach needs to be followed in building design and operation. There should be avenues to implement adaptive thermal comfort standards.
- Operative and effective temperature based approach should be used to evaluate thermal environment that covers the combined effect of air temperature, humidity, air velocity, radiant temperature, clothing and activity.
- Higher air velocity offers the opportunity to maintain thermal comfort at higher air temperature.
- Humidity control measures should be implemented according to the purpose for which the building is occupied.
- Since mould and mildew proliferate when humidity goes unchecked and can be potentially hazardous for the health of the inhabitants, both low and high humidity need to be avoided.
- The focus in building design and operation should be on vapor barrier treatment and avoiding negative room pressures, apart from controlling the humidity to prevent mould and mildew.
- Lighting standards need to be improved for providing additional guidance on appropriate spectrum selection for the particular task and environment.
- Noise mitigation measures are required to limit the impact of noise to human health. This requires standardized noise levels, both generated inside the building and external noise transferred via the building envelope.
- Building design decisions for maintaining IEQ from the health perspective should be inter-dependent with HVAC system sizing and operating energy consumption.
- ISHRAE recognises the value of gaining direct feedback from occupants to gauge occupant satisfaction and experience of IEQ aspects to augment physical measurement of IEQ attributes, and recommends its inclusion for Post Occupancy Evaluation studies.

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About IEQ Committee Members

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Dr. Jyotirmay Mathur is a Professor in mechanical engineering at Malaviya National Institute of Technology, Jaipur. His research interests are energy efficiency, low energy cooling systems and energy policy modeling. He has 23 years of experience in teaching and research. His current activities include studies on adaptive thermal comfort, radiant cooling systems, and energy codes and standards.

Maija Virta has over 25 years of experience in construction and HVAC industry spread over the globe. She specialises in sustainable building policies and technology, and has been involved in developing user-centric IEQ measurement, verification and post-occupancy evaluation processes. Prior to moving to India, Maija was the CEO of Green Building Council of Finland. She has authored many books and publications, and presented papers and lectures in forums stretching across three continents.

B. Gautham Baliga is director at OPAL HVAC Engineers Pvt. Ltd., which specialises in design-build of pharmaceutical, healthcare and industrial HVAC systems. He has been involved in projects with special focus on humidity issues. He is a mechanical engineer from IIT Kharagpur and worked with Voltas for 8 years. He is on the Editorial Board of *Air Conditioning and Refrigeration Journal*, and is a member of ISHRAE Technical Committee, Chair of Certifications Committee, and ISHRAE Distinguished Lecturer.

Leena Thomas is Associate Professor, Strand Leader in Environmental Studies at the School of Architecture, University of Technology, Sydney. Her research focuses on building performance, sustainable architecture, IEQ and post-occupancy evaluation with particular expertise in Indian and Australian contexts. Her expertise is recognised through government and industry funded research grants, and invitations to advise government and industry bodies on policy and dissemination of research outcomes and to serve on design and industry award juries.

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Barun Aggarwal is director at BreatheEasy, a division of Paharpur Business Centre. An ISHRAE member and a certified Climate Reality Leader trained by former US Vice President Al Gore, he specialises in IAQ, specifically testing, evaluation, remediation, occupant comfort and wellness. He has implemented NABERS (PALM), USGBC and is working on the first building in India for WELL certification. He brings disruptive and sustainable technologies in air and water. He has presented in various national and international forums.

V. Manjunath is a mechanical engineer with over two decades of HVAC experience, with expertise in implementing stage gate system for introduction of new products and services. He has been associated with BIS, ISHRAE, RAMA, BEE, etc. for developing standards, and was a member of ISHRAE-RAMA Standards Committee for liquid chillers. He was in the Principal Secretariat for solar photovoltaic standards development for MNRE's Jawaharlal Nehru National Solar Mission, and has been associated with regulators in the Middle East.

Rahul Aeron is National Sales Manager at Desiccant Rotors International, responsible for selling IAQ related products. He is a mechanical engineer from Raipur University, with more than 20 years of experience in sales of HVAC systems. His areas of interest are ventilation systems, air purification systems, RH control strategies and energy saving technologies.

Nitin M. Deodhar graduated with honors in mechanical engineering in 1987 and is a gold medalist with masters in environmental engineering. He has over 13 years of contracting experience, and has been in consulting for over 14 years now. He is interested in design of research oriented and novel greenfield projects, and is involved in detailed engineering of fitout projects. He is a LEED AP of USGBC and a certified Energy Manager by BEE.

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Conclusion and Recommendations

- ISHRAE has recognized that the issue of indoor environment quality, including thermal, lighting and acoustic comfort and indoor air quality, needs urgent attention of designers, operators and building owners. It has also identified the necessity of extensive field studies covering different building types, locations, age groups and work profiles. Such studies should be conducted following international protocols for measurements of IEQ parameters, a transparent methodology of analysis and, finally, validation of research findings. Further, the requirement of linking several standards, viz. thermal comfort, indoor air quality, daylighting and acoustic standards, in the Indian context may also be looked so that a comprehensive IEQ classification/standard can be prepared for Indian buildings keeping energy efficiency under active consideration.
- ISHRAE needs to increase the general awareness of the health effects of poor IEQ and relevant solutions to improve it among the public and building professionals.
- Additional research is required to determine the relative significance of the visual and health implications of typical light exposures on circadian, neuroendocrine, and neurobehavioral patterns.
- Integrated building design needs to be promoted in the building community to ensure that maximum benefit is derived from all IEQ parameters, especially daylighting and artificial lighting to meet the holistic needs.
- A common IEQ standard and classification criteria for buildings is required in India to address the above mentioned issues comprehensively. This is necessary for allowing users, owners and designers to make well-informed decisions.
- ISHRAE (Indian Society of Heating, Refrigerating & Air Conditioning Engineers) has formed a national level committee focused on Indoor Environment Quality issues in India. Members of this committee have multi-disciplinary knowledge of the different aspects of IEQ both in India and abroad. The focus of this committee is on developing India-specific research/technical reports and recommendations for IEQ management covering indoor air quality, thermal comfort, lighting and acoustic conditions while ensuring proper use of energy resources. ISHRAE also endorses the importance of past and ongoing research efforts related to IEQ in Indian institutes and invites more and more such organizations and individuals to take part in this endeavour.

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Disclaimer

ISHRAE's position is based on all referenced works with the year of release as mentioned. Any revisions in the referenced works shall not be automatically deemed to be accepted by ISHRAE unless specifically confirmed or updated by ISHRAE.

In case of any differences between the referenced works and ISHRAE's position, the user is requested to bring these differences to the notice of ISHRAE's Technical Committee; however, ISHRAE's position, where explicitly stated, shall apply. ❄