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A Review on Indoor Environment Quality of Indian School Classrooms

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Abstract: The progress of Indoor Environmental Quality (IEQ) research in school buildings has increased profusely in the last two decades and the interest in this area is still growing worldwide. IEQ in classrooms impacts the comfort, health, and productivity of students as well as teachers. This article systematically discusses IEQ parameters related to studies conducted in Indian school classrooms during the last fifteen years. Real-time research studies conducted on Indoor Air Quality (IAQ), Thermal Comfort (TC), Acoustic Comfort (AcC), and Visual Comfort (VC) in Indian school classrooms from July 2006 to March 2021 are considered to gain insight into the existing research methodologies. This review article indicates that IEQ parameter studies in Indian school buildings are tortuous, strewn, inadequate, and unorganized. There is no literature review available on studies conducted on IEQ parameters in Indian school classrooms. The results infer that in India, there is no well-established method to assess the indoor environmental condition of classrooms in school buildings to date. Indian school classrooms are bleak and in dire need of energy-efficient modifications that maintain good IEQ for better teaching and learning outcomes. The prevailing COVID-19 Pandemic, Artificial Intelligence (AI), National Education Policy (NEP), Sick Building Syndrome (SBS), Internet of Things (IoT), and Green Schools (GS) are also discussed to effectively link existing conditions with the future of IEQ research in Indian school classrooms.

Keywords: classroom; ventilation; COVID-19; indoor air pollution; sick building syndrome; artificial intelligence; thermal comfort; visual comfort; acoustic comfort; indoor air quality

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1. Introduction

The prime aim of any building is to minimize the negative impacts of the outer environment on its occupants by creating a healthy, comfortable, and productive indoor environment [1]. The performance of the indoor environment is described as Indoor Environmental Quality (IEQ) and depends upon external environmental factors such as exterior air quality [2], outer temperature [3], wind speed, humidity [4], noise [5], outer lux levels [6], etc. In 2020, nine out of the top ten most polluted cities were in India, and thirty-five out of the top fifty world's most populated cities were also in India. Out of one hundred and six countries, India ranks third after Bangladesh and Pakistan in first and second, respectively, for the worst air quality [7]. The United States Air Quality Index (US AQI) value for India is 141 for the year 2020 [7], which is unhealthy for sensitive groups such as children, people with respiratory diseases, and old people, as shown in Figure 1 [8]. Apart from poor air quality conditions not only India but worldwide, the whole world is also facing problems associated with climate change and the temperature increase [9].

Earth's average temperature has increased about 1.02 degrees Centigrade during the 20th century. The Intergovernmental Panel on Climate Change (IPCC) forecasts a temperature rise of 1.4 to 5.6 degrees centigrade over the next century [10]. Interestingly, according to a report by the National Programme for the Prevention and Control of Deafness (NPPCD), it was estimated by the World Health Organization (WHO) that in India, approximately 63 million people (6.3%) are affected by noise pollution and suffer from significant hearing impairment [11]. As per the 58th National Sample Survey (NSS), 291 persons out of every lakh of population were found to have severe-to-profound hearing losses in India [12]. According to the national survey report, there was a large percentage of 0–14-year-old children in the affected population. The survey revealed that there may be many more cases of milder degree and unilateral (single-sided) hearing losses [13]. As per the 2011 Census, 425.9 people per one lakh of population had prevailing hearing problems [14]. All these facts point towards the increasing need to consider IEQ in Indian buildings, as occupants tend to spend more than 90% of their time indoors [15].

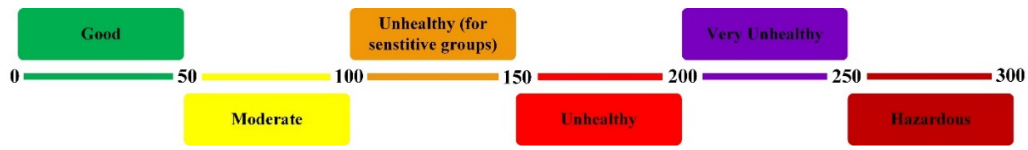

Figure 1. US air quality index color coding and classes.

The assessment of IEQ in school classrooms is of prime concern as students and teachers spend 4–8 h during weekdays in schools, which is one-third of their total time [16]. With increasing education levels, students require higher levels of concentration and more thinking [17]. According to a report on school statistics by the Government of India (GOI), the government is playing a major role in providing school education with approximately 55% of 1.4 million schools in the country [18]. The Indian "Right to Education Act, 2009" recommends 200–220 days' academic year for school education with approximately 800–1000 teaching hours according to different grades [19]. Mandatory teaching hours in different countries as mentioned by OECD [20] are presented in Figure 2.

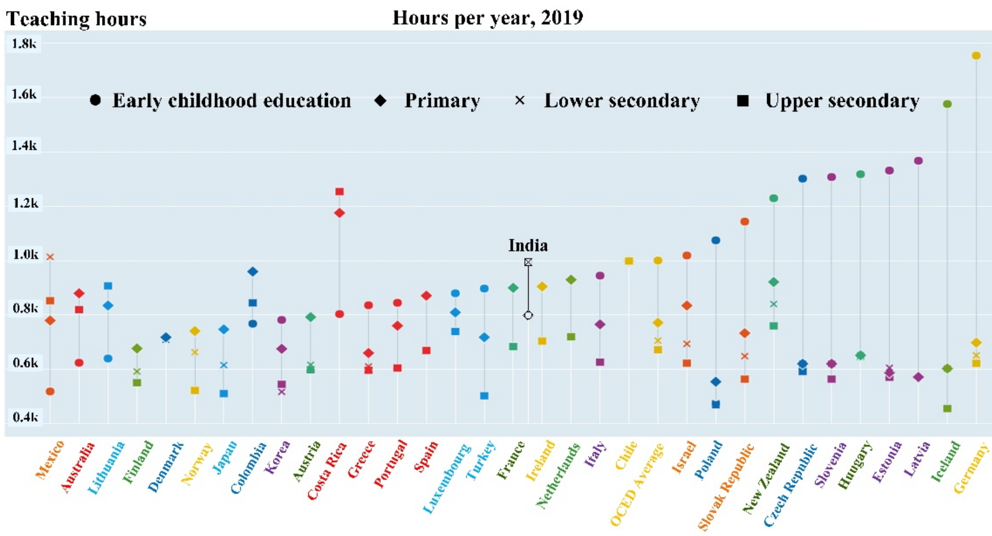

Figure 2. Teaching hours per year in different countries [20].

The average person spends the initial 14–15 years of his/her life, from 3 to 4 years of age until 17 to 18 years, in school buildings irrespective of the country, as shown in Figure 3. In India, according to the new National Education Policy (NEP), 2020 [21], school education is divided into four categories. The new pedagogical and curricular structure of India is 5-3-3-4; i.e., an initial 5 years at the age of 3–8 years in foundational education (preschool and class 1–2), then 3 years age 8–11 years in preparatory education (class 3–5), then 3 years age 11–14 years in middle education (class 6–8), and lastly, 4 years at the age of 14–18 in secondary education (class 9–12) as shown in Figure 3.

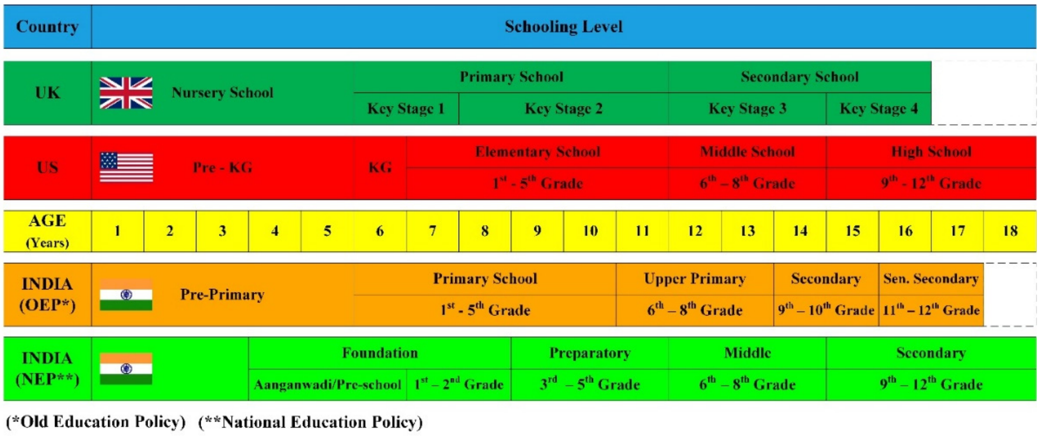

Figure 3. Structure of education system of different countries.

Children are the most sensitive group severely affected by diseases as their immune system is weaker than adults. They breathe a higher volume of air than adults according to their body weight as their organs are in the development stage [22]. Children's metabolic rate is also different from that of adults. According to the United Nations Educational, Scientific, and Cultural Organization's (UNESCO) Institute for Statistics Data [23], the total number of enrolled learners in the Indian education system is 320,713,810 (including higher education), which is approximately 25% of the Indian population, in which 10,004,418 are at the pre-primary level, 143,227,427 are at the primary level, and 133,144,371 are at the secondary level. Therefore, it is essential to study IEQ in school classrooms as approximately one-fourth of the country's population is related to this study area. The classrooms can be classified according to Figure 4 for better understanding.

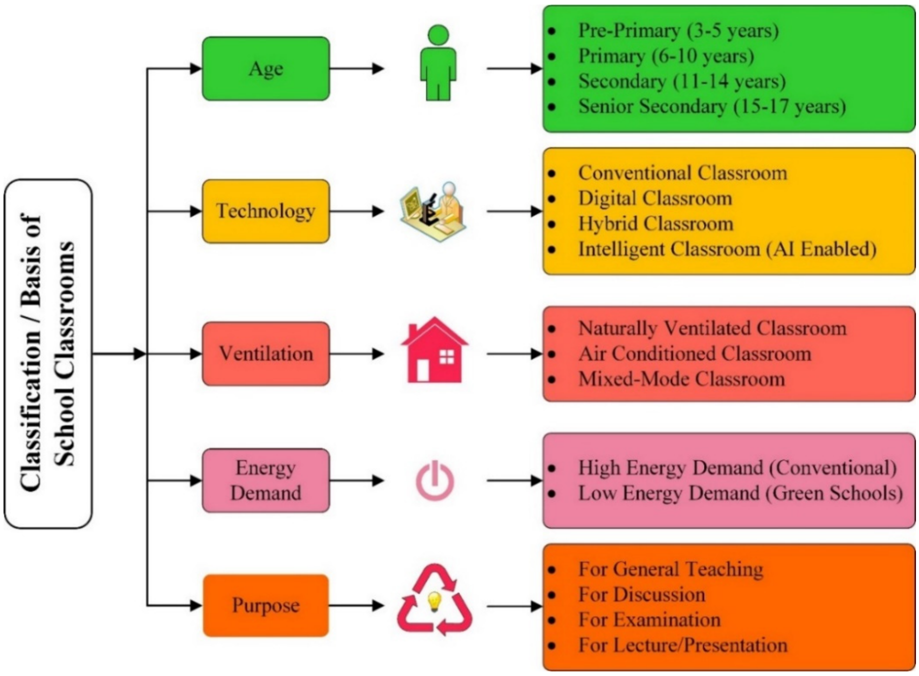

Figure 4. School classroom classification.

Similarly, another reason for the focus on IEQ studies in Indian schools is due to Building-Associated Illness (BAI) within them. BAI is classified into two types, namely Sick

Building Syndrome (SBS) and Building-Related Illness (BRI) [24]. SBS is subjective in nature, highly prevalent within the reported area, and reversible [25]. However, BRI is irreversible and affects the occupant long even after leaving the corresponding sick building or area [26]. General SBS symptoms are mucous membrane irritation [27,28], neurotoxic effects [29], asthma [30], skin-related symptoms and irritation [31], gastrointestinal complaints [32], etc. The most common symptoms and related illnesses due to BAI are presented in Figure 5. Alongside the prevalence of BAI, COVID-19 spread among students makes it important to study IEQ in Indian school classrooms, especially Indoor Air Quality (IAQ) [1], for a better understanding of the current and future demand of the building industry in the education sector.

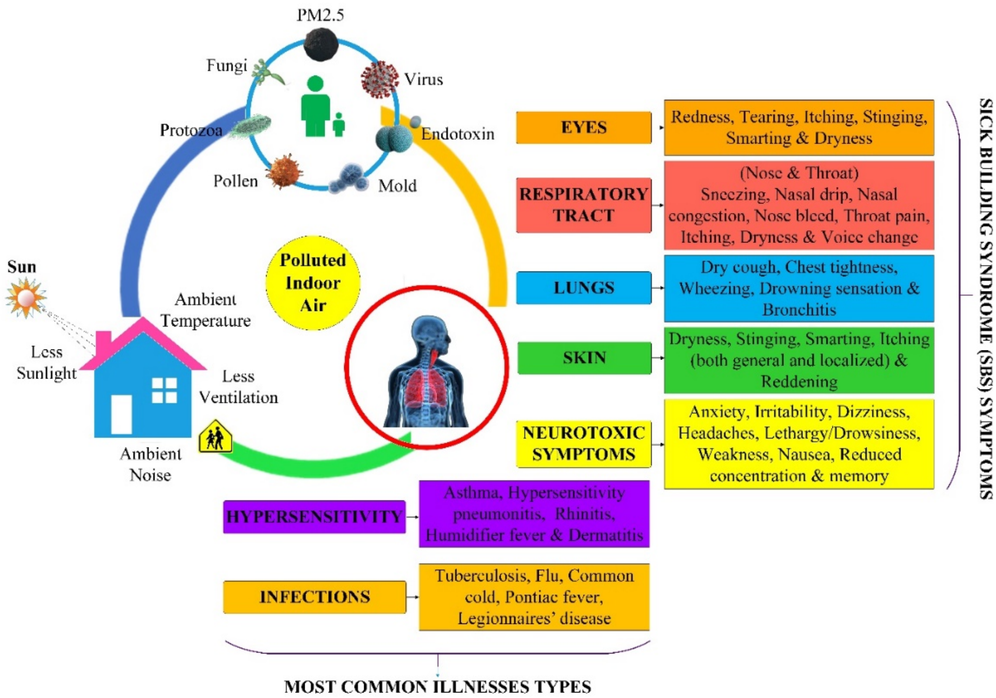

Figure 5. BAI's related symptoms.

Therefore, helping in the creation of a better and safer learning environment for students and teachers in the present and future is the main motivation behind this review of existing studies.

Objectives of the Study

According to the reviewed literature, there is no literature review regarding IEQ parameter studies conducted in Indian school classrooms. However, various researchers have tried to determine suitable limits of various individual IEQ parameters (TC, IAQ, VC, AcC) [33]. The objectives of the current state-of-the-art review are threefold; (i) To understand the existing knowledge based on real-time Indian studies of IEQ parameters in school classrooms, (ii) to identify knowledge gaps to perform further research on IEQ parameters in Indian schools, and (iii) to identify and integrate advanced research areas with IEQ that can potentially increase the impact of IEQ research in school buildings.

2. Review Methodology

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach is used as the review methodology in this review of studies. Figure 6 shows the adopted working methodology. Data were extracted from various databases based on keywords, abstract, and conclusions, focusing on IEQ in Indian school classrooms and related case studies. A few full review articles and some research articles on the basis of title and abstract were considered for the final selection. After detailed analyses of the thirty-seven included articles, all the ideas generated through the understanding of existing knowledge were organized and linked together to form a systematic review, which was then followed by a detailed discussion, conclusion, and future directions.

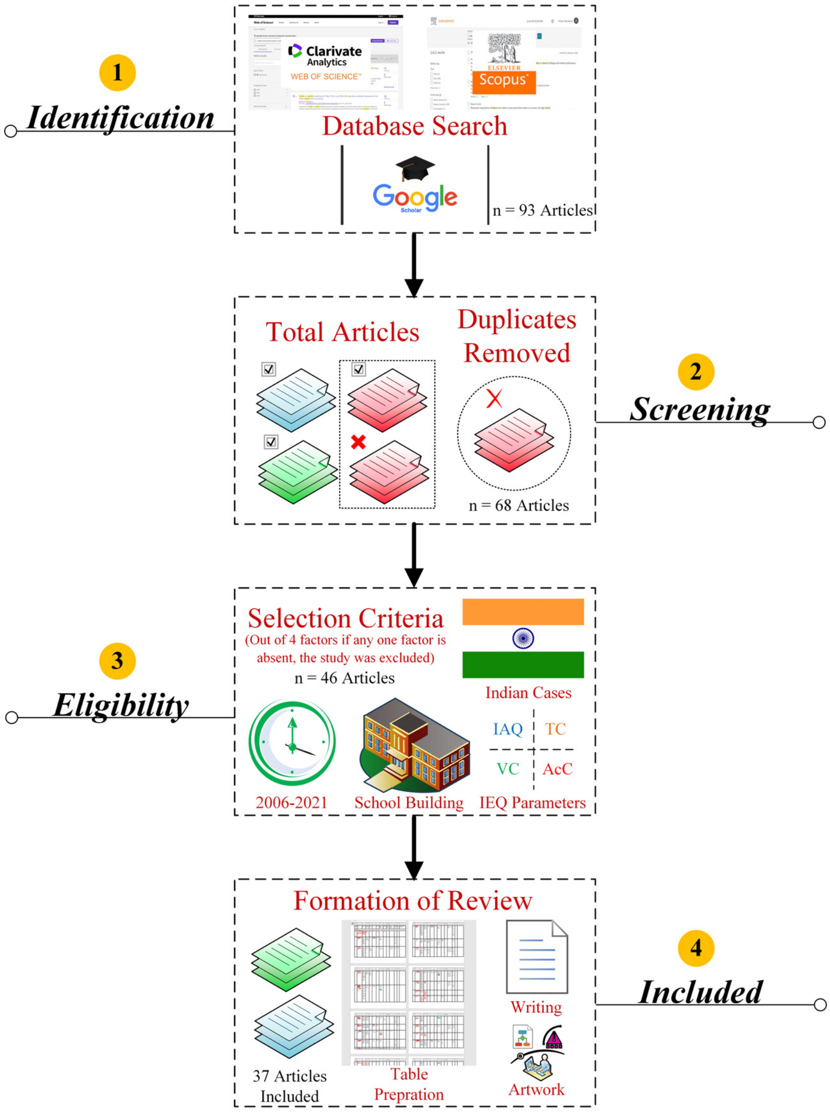

Figure 6. PRISMA review methodology.

3. Indian Climatic Classification and Indoor Environmental Quality

India has about 1.35 billion people residing in a geographical area of 3,287,263 km^2 [34,35], making it the seventh most densely populated country in the world out of 195 countries [36,37]. Being a multi-seasonal country with a wide stretch from east to west and north to south, temperature, humidity, and wind speed varied dynamically in India. The National Building Code (NBC) 2016 [38] classified India into five climate zones, i.e., hot and dry, warm and humid, temperate, cold, and composite. The percentage area of Indian land under each climate zone is shown in Table 1 with the classification criteria based on NBC 2016. The window-to-wall ratio and outer lux levels are also tabulated as per the Energy Conservation Building Code (ECBC) 2017 [39] recommendations.

Table 1. Indian climatic zones and associated data from NBC 2016 and ECBC 2017.

	NBC 2016 [38]				ECBC 2017 [39]	
Climatic Zone	**Mean of Monthly**		**Climatic Area**		**Widow to Wall Ratio**	**Outer Lux Levels**
	Temperature	**Relative Humidity**	**km^2**	**%**		
Hot-Dry	>30 °C	<55%	545,686	16.60	20–30%	10,500
Warm-Humid	>30 °C >25 °C	>55% >75%	1,160,404	35.30	30–40%	9000
Temperate	25–30 °C	<75%	9862	0.30	40%	9000
Cold	<25 °C	All values	364,886	11.09	20–30%	6800
Composite	When ≥6 months do not fall in any of the above categories		1,206,426	36.70	40–50%	8000

3.1. IEQ and Its Parameters

IEQ is the built environment quality of any indoor space concerning the wellbeing and health of the occupant using that space [40]. It is made up of several parameters, such as Indoor Air Quality (IAQ), Acoustic Comfort (AcC), Thermal Comfort (TC), Visual Comfort (VC), furniture orientation, electromagnetic waves, vibrations, etc. [41]. Four important parameters, IAQ [42], AcC [43], TC [44], and VC [45], are considered under the scope of this article and are depicted in Figure 7. This review paper contains four major sections. The general equation (without weights) for overall IEQ is depicted in Equation (1) here:

$$IEQ = TC + VC + IAC + AcC, \tag{1}$$

where IAC is the Indoor Air Comfort and is the combination of IAQ and Ventilation.

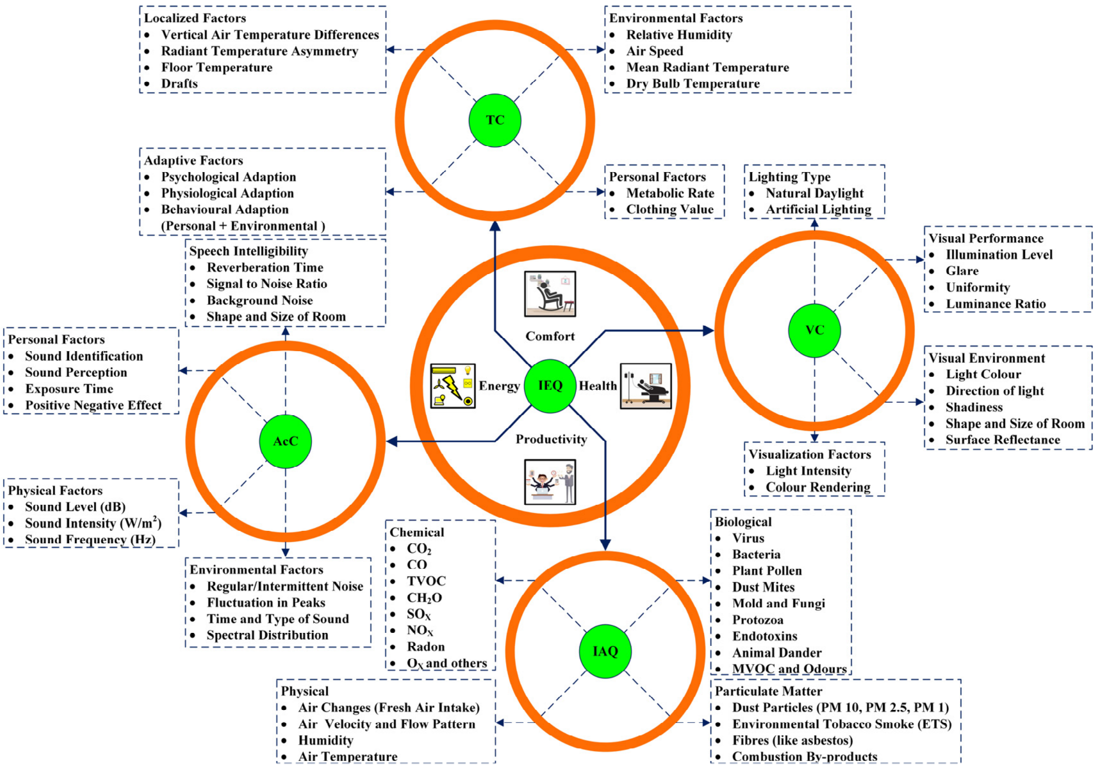

Figure 7. IEQ parameters and associated sub-parameters.

IEQ parameters have various sub-parameters (or sub-factors) on which they depend, and these parameters and sub-parameters are presented in Figure 7. Some of the sub-parameters of IEQ parameters have a major impact and some have a minor impact, but when two or more sub-parameters of similar or different parameters occur in combination, the impact is greater, and it is critical to identify the exact sub-parameter primarily responsible for that impact.

3.1.1. Thermal Comfort (TC)

Thermal comfort (TC) is an occupant's mental status, which expresses the level of satisfaction with the thermal surroundings. TC depends on four environmental factors, Relative Humidity (RH) [46–50], Mean Radiant Temperature (MRT) [51–53], Dry Bulb Temperature (DBT) [54–57], and air speed [58–61] along with two personal factors, clothing rate [62–66] and metabolic rate [63,67–72]. There are two well-accepted models for predicting TC in any building, namely the Predictive Mean Vote (PMV) and the Adaptive model for TC [1,73,74]. The PMV model is also known as the heat-balance model or the Laboratory-based model. Povl Ole Fanger developed the PMV model in the 1970s [75] and it works well with Air-Conditioned (AC) buildings. The International Organization for Standardization (ISO) ISO-7730 [76] considers the PMV model as their thermal comfort model. The Adaptive model was created by Richard De Dear and Gail S. Brager in 1998 [77], and this model considers that the human body is adaptive in nature and can modify itself according to the surrounding environment to an extent. This model works well with Naturally Ventilated (NV) buildings. Most of the Indian school buildings are naturally ventilated [1] so the adaptive approach is more suitable. The adaptive model is presented in Equation (2) [78,79]. It is a linear regression of the indoor comfort temperature (T_c) and the outdoor air temperature ($T_{pma(out)}$). For example, if the $T_{pma(out)}$ is 40 °C, then Tc will be perceived by the occupants at 30.2 °C according to the above adaptive model.

$$T_c = 0.31\ T_{pma(out)} + 17.8, \tag{2}$$

3.1.2. Indoor Air Quality (IAQ)

The quality of air inside and around the building is known as the Indoor air quality [80–82]. IAQ depends upon the humidity [83–87], ventilation rate [88–91], temperature [83,92,93], several gases [83–91], biological contaminants [94,95], and the presence of particulate matter [96–99]. A combination of factors (physical, chemical, biological, and particulate matter) and dynamic interactions among parameters make it challenging for occupants to identify IAQ-associated problems [100]. Outdoor pollution significantly impacts the quality of indoor air in naturally ventilated buildings [101]. SBS is primarily associated with IAQ [25]. Ventilation affects IAQ as it is the process of replacing indoor vitiated air with fresh exterior air and maintaining air motion inside the space [102].

3.1.3. Visual Comfort (VC)

Occupant wellbeing influenced by the surrounding visual environment inside the occupied building space is considered the visual comfort of that space and it can be subjectively accessed [103,104]. VC is affected by natural daylight [105–108], illumination level [109–111], uniformity of light [112,113], the color of light [114–116], etc. Discomfort due to glare [117,118], non-uniform lighting [119,120], and lack of required lux levels affect students' performance in the classroom [121]. Symptoms such as frequent headaches [122–126], eye strain [127–129], and weak eyesight [130] are related to VC in classrooms. Circadian rhythms are directly affected by lighting, thus creating problems in biological processes and altering occupants' mood [131]. The general circadian rhythm [132–134] of a normal healthy person is presented in Figure 8, whereas Figure 9 shows both the interrelation and difference among the commonly used terms in visual comfort that create a dilemma in early individuals interested in this area.

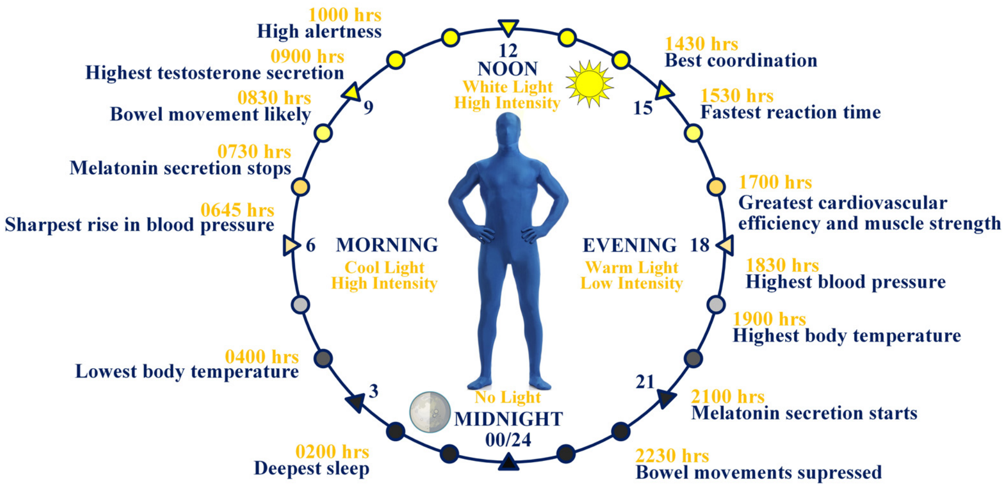

Figure 8. Natural daylight and healthy human circadian rhythms.

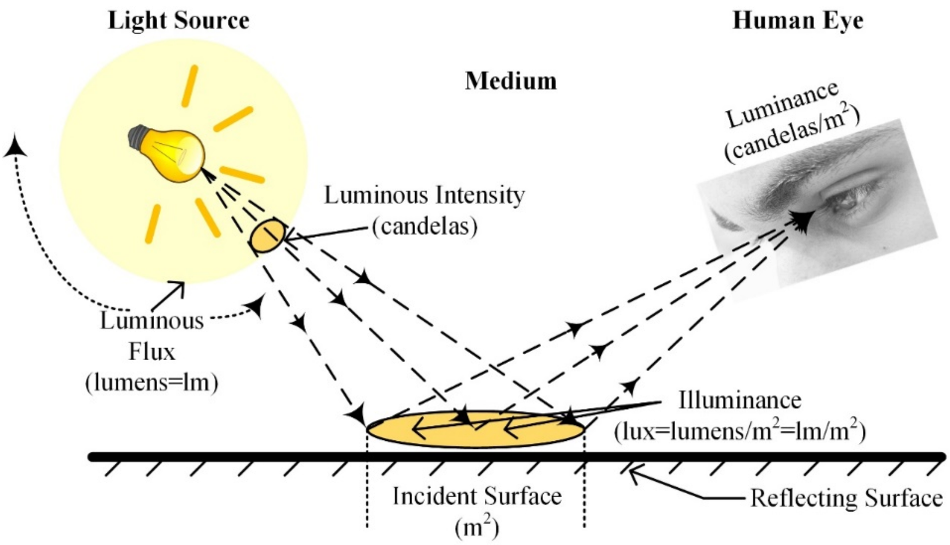

Figure 9. Interrelation and difference among light-measuring terms.

3.1.4. Acoustic Comfort (AcC)

Acoustic comfort refers to the quality of the building and its ability to safeguard its residents from surrounding noise and offer them a better, secure, and uninterrupted acoustic environment in which they can communicate conveniently [135–140]. Sound pressure levels [141,142], sound frequency [141–144], source distance [145,146], sound absorption [147], insulation [62,65,143], and Reverberation Time (RT) [147–149] are some of the factors that affect AcC in the occupied space. Noise can be classified as five types, namely steady, fluctuating, tonal, intermittent, and impulsive noise [38]. Speech intelligibility depends mainly upon the Reverberation Time (RT) and the Signal-to-Noise Ratio (SNR) [150]. Reverberation undesirably affects consonant and vowel perception [151]. However, consonants have more adverse effects in perceiving speech meaning than vowels [152,153]. In general, a significant part of the speech sound is made up of consonants. RT is determined by Sabine's formula presented in Equation (3) [154] where V is the room volume in cubic feet, A is the total effective square footage of the absorption area, and T is the required time in seconds for a 60 dB sound decay after the source has stopped.

$$T = 0.049 \times (V/A), \tag{3}$$

Acceptable noise levels and the reverberation time recommended by various organizations for different types of classroom conditions are presented in Table 2.

Table 2. Acceptable indoor noise levels and reverberation time in classrooms.

Standard (Year) [Ref.]	Classroom Specification	Noise Level (dB)	Reverberation Time (s)
WHO Guidelines [155]	General	35 dB LA_{eq}	0.6
NBC (2016) [38]	General	40–45 dBA	0.6–1.1
ANSI S12.60 (2002) [156]	Volume < 283 m^3	35 dB $LA_{eq,1h}$	0.6
	Volume = 283 m^3 to 566 m^3	35 dB $LA_{eq,1h}$	0.7
	Volume > 566 m^3	40 dB $LA_{eq,1h}$	-
Building Bulletin 93 [157]	Primary School	35 dB $LA_{eq,30min}$	<0.6
	Secondary School	35 dB $LA_{eq,30min}$	<0.8
	Lecture Room (>50 students)	30 dB $LA_{eq,30min}$	<1.0
	Hearing Impaired Class	30 dB $LA_{eq,30min}$	<0.4
ISHRAE (2019) [158]	Area < 70 m^2	40 dBA (max.)	<0.6–<1.0
	Area > 70 m^2	35 dBA (max.)	<0.6–<1.0
	Large Lecture Rooms	35 dBA (max.)	<0.6–<1.0
ASHA (1995) [159]	Hearing Impaired Class	30 to 35 dBA SNR > 15 dB	< 0.4
IS 1950 (1962) [160]	General	45–50 dB	-
BATOD (2001) [161]	Hearing Impaired Class	<35 dB(A) SNR > 20 dB for 125 Hz to 750 Hz and SNR > 15 dB for 750 Hz to 4000 Hz	<0.4 (125 Hz to 4000 Hz)

When IEQ parameters are carefully balanced, a building can be both productive and protective. In India, there are two public regulatory bodies, namely NBC and ECBC, but neither of them specify any codes for IEQ in school classrooms. Therefore, for basic knowledge on 'until-now!' and for future directions, 'what is next?', this review helps in understanding the state of the art and tries to provide some comprehensive outcomes of all the studies conducted in India regarding IEQ in school classrooms.

4. Indoor Environmental Quality in Indian School Classrooms

4.1. Thermal Comfort (TC) in Indian School Classrooms

Primarily, Indian school classrooms are Naturally Ventilated (NV), and their thermal comfort is affected by the outside environment [1]. In India, the foundation work on thermal comfort was conducted by the scientists M.R. Sharma and S. Ali [162] of CSIR—the Central Building Research Institute (Roorkee)—in the 1980s. They proposed the Tropical Summer Index (TSI) to determine thermal comfort in hot–dry and warm–humid conditions. However, the TSI for other climates is still in the development stage. The TSI (°C) depends on the wet bulb temperature (t_w) in °C, the globe temperature (t_g) in °C, and the airspeed (V) in m/s as presented in Equation (4) [38,162,163].

$$\mathrm{TSI} = 0.308 \times t_w + 0.745 \times t_g - 2.06 \times \sqrt{(V + 0.841)}, \quad (4)$$

In NBC 2005 [164] and NBC 2016 [38], thermal comfort conditions (i.e., humidity 30–70%, temperature 25–30 °C, and air speed 0–2 m/s) are based on the TSI model. After the development of TSI, for more than fifteen years the progress has been quite slow in this domain in India. In the last two decades, the progress in this domain by Indian researchers is quite commendable. However, most of the studies are performed in residential and commercial buildings [1,165]. School buildings have been excluded from indoor comfort studies in the country until now [1]. While considering Indian school classrooms, a total of six articles were published on thermal comfort in the last fifteen years, out of which only two articles are based on real-time studies conducted in school classrooms and the other four are review and informative articles.

Kala Choyimanikandiyil [166,167] explored thermal comfort and linked it to Indian school classrooms in warm–humid climates through articles in 2013 and 2016. A real-time TC assessment study in an Indian school classroom was performed in the composite climate by Aradhana Jindal. Aradhana [168] examined the TC of NV school classrooms in Ambala, India during the winter and monsoon season of 2015–2016. The study contains both objective and subjective measurements. One-hundred and thirty students of the 10–18-years-old age group responded to this study. In this study, the neutral temperature was recorded at 27.1 °C, with the comfort temperature ranging between 15.3 °C and 33.7 °C for an 80% acceptance rate. The comfort temperature recorded in this study is significantly different from International and National standards. The reason behind that is all the standards are based on adult perceptions, and heat tolerance is higher in children. The regression line for the slope is plotted between the thermal sensation (t_{sv}) and the indoor operative temperature (T_{op}). The regression models obtained in this study are shown below in Equations (5)–(7) [168].

$$t_{sv} = 0.056 \times T_{op} - 1.53,\ R^2 = 0.22\ \text{(combined)}, \quad (5)$$

$$t_{sv} = 0.19 \times T_{op} - 5.54,\ R^2 = 0.18\ \text{(monsoon)}, \quad (6)$$

$$t_{sv} = 0.18 \times T_{op} - 3.52,\ R^2 = 0.36\ \text{(winter)}, \quad (7)$$

Aradhana conducted a similar type of yearlong research [18] in three naturally ventilated schools in Chandigarh, Ambala, and Panchkula (all are in the composite zone as per NBC 2016), and the neutral temperature was explored for both winter and summer seasons. The author found variation from her previous study where the neutral temperature was 27.1 °C. The neutral temperatures obtained for winter and summer were 19.4 °C and 28.2 °C, respectively, for Indian students. The study also explored the comfort temperature ranging between 16 °C and 33.7 °C for students of NV classrooms in a composite climate at the age of 10–18 years. The regression model for t_{sv} and T_{op} plotted in this study is presented in Equations (8) and (9) [18].

$$t_{sv} = 0.17\ T_{op} - 4.95,\ R^2 = 0.19\ \text{(summer)}, \quad (8)$$

$$t_{sv} = 0.23\ T_{op} - 4.53,\ R^2 = 0.51\ \text{(winter)}, \quad (9)$$

A thermal comfort model obtained by linear regression is also proposed in this study for an NV school classroom in a composite climate, which indicates a unit change in neutrality with each variation of 1.85 degrees centigrade in the prevailing mean outdoor temperature ($T_{pma(out)}$) as shown in Equation (10) [18].

$$T_n = 0.54 \times T_{pma(out)} + 12.93, \quad (10)$$

Manoj Kumar et al. [169] reviewed eighty-one articles based on a thermal comfort study in classrooms globally. They determined that primary school children were least affected by temperature changes as their body is more adaptive than adults and secondary school students. Based on their findings, they proposed comfort equations for primary and secondary students as presented in Equations (11) and (12) [169], respectively.

$$T_{cop\_pri} = 0.28 \times T_{out} + 17.02\ (N = 17;\ R^2 = 0.21), \quad (11)$$

$$T_{cop\_sec} = 0.46 \times T_{out} + 14.33\ (N = 16;\ R^2 = 0.75), \quad (12)$$

T_{cop_pri} is primary school classrooms' operative comfort temperature, T_{cop_sec} is secondary school classrooms' operative comfort temperature, and T_{out} is the daily mean outdoor temperature.

Manoj Kumar et al. [17] reviewed the last fifty years of literature on thermal comfort in classrooms. The review paper is quite helpful in tracing the research conducted in TC assessment in classrooms throughout the world. Based on the existing literature, adaptive thermal comfort equations are proposed for primary and secondary classrooms as shown in Equations (13) and (14) [17].

$$T_{cop\_pri} = 0.22 \times T_{out} + 18.01 \ (N = 21; R^2 = 0.17), \quad (13)$$

$$T_{cop\_sec} = 0.47 \times T_{out} + 14.11 \ (N = 18; R^2 = 0.77), \quad (14)$$

However, the previous studies are not sufficient for confirming any comfort temperature range. More real-time and data-driven research with both subjectivity and objectivity is needed to find more precise results and prepare more reliable models that can predict student's perceptions in a given environment. Moreover, none of the studies consider the effect of other IEQ parameters over TC. The Hawthorne effect and students' TC at their homes are not considered. However, in real time, these factors can significantly affect students' comfort perception in classrooms. The TC impact on students' and teachers' performance is also an important area to be considered as it has been excluded from the past research in this country.

4.2. Indoor Air Quality (IAQ) in Indian School Classrooms

IAQ has been the most-researched parameter in Indian school classrooms over the last fifteen years. IAQ research in India shows that factors such as CO_2, particulate matter, Volatile Organic Compounds (VOCs), and other gases [16,22,170–184] are considered important in school classrooms by researchers. The review reveals that much attention was initially given to particulate matter study in classrooms. Research trends show that the current focus of researchers is the CO_2 concentration inside the classroom. However, ventilation rates inside the classrooms need more attention. Ventilation is the main factor to be considered for preventing airborne disease transmission inside the classroom. Classrooms have a generally high density and low ventilation rate due to space restrictions, human capabilities, closed windows and doors, as well as the negative effect of other IEQ parameters on students and teachers when balancing IAQ (such as noise from open windows, particulate coming from open windows, fan noise, etc.).

Nilima Gadkari et al. [170] examined the source contribution of personal respiratory particulate matter in school classrooms. Fifteen subjects (initially sixteen) from three naturally ventilated higher secondary schools of Chhattisgarh were considered for this study. The authors explored that ambient outdoor air conditions (mainly road traffic dust) affect students in classrooms. Radha Goyal et al. [16] tested IAQ by the objective technique in the school classroom of Delhi. Year-long objective testing in the naturally ventilated junior school section (Class 1–8) was executed. The Respirable Suspended Particulate Matter (RSPM) concentration was found higher than the prescribed limits, which shows potential health hazards. The building envelope does not protect students from outer pollution effectively because open doors and windows increase classroom permeability. Ventilation rates and student activity inside the classroom also influence the concentration of PM10 particles in the air due to the re-suspension mechanism. The authors observed that meteorological factors significantly impact IAQ in classrooms.

Nilima Gadkari et al. [171] studied the indoor ambient Particulate Matter (PM) in three naturally ventilated higher secondary schools at Bhilai and Durg. During the summer of 2003, a combination of twenty-seven teachers, twenty-two students, and three office staff, cumulatively fifty-two subjects, participated in the study by completing time/activity diaries. A regression showed a significant relation between indoor and outdoor ambient PM levels. The breathable PM level in all schools exceeds the limit (i.e., 60 $\mu g.m^{-3}$) mentioned in Indian National Ambient Air Quality Standards (NAAQS) [185]. Two schools situated near the industrial area show PM levels five to six times higher than the prescribed limits, creating health hazards in these classrooms.

Mahima Habil et al. [172] evaluated IAQ and the ventilation rate in naturally ventilated schools in Agra during the winter and summer seasons. Three hundred subjects participated in a questionnaire survey to test health impacts (dry flaking skin, dizziness, etc.) due to CO_2 concentration and exposure to PM in the classroom. PM levels tested higher in winters than in summer in all the classrooms. Indoor–outdoor (I/O) ratios were higher in most of the cases except for one school situated in a residential area. A high I/O ratio indicates prevailing poor IAQ conditions in those classrooms where schools are situated near busy roads. The I/O ratio decreases with particle size increment. Damaged walls, dirty floors, old furniture, dirty dusting material, shoe dust, chalk dust, and resuspension of old settled particles due to student activities are the main reason for higher indoor PM levels. The main reason for a higher CO_2 concentration inside the classroom is exhaled breath, as more students results in a higher CO_2 concentration.

Radha Goyal et al. [173] performed IAQ modeling for PM particles in a naturally ventilated Indian school building. The IAQ model proposed in this study is based on the mass-balance method, coded in C++ language, and named "HEMANYA". The authors reported high seasonal variation in indoor PM. In winter, PM levels were three to five times higher than in summer due to poor dispersion and increased surface concentrations inside the classroom. Deepanjan Majumdar et al. [174] tested settled chalk dust for the assessment of fine particles in indoor air along with particle size distribution in the classroom during the dusting and writing process. Three types of chalks were tested for PM_1, $PM_{2.5}$, PM_5, and PM_{10} size particles. Student's activities severely affect the resuspension of fine particles in the classroom. Long-duration low-level exposure to PM is also harmful to occupant health. Middle-age teachers and primary students are prone to respiratory malfunctions due to regular exposure to fine particulates.

V.S. Chithra et al. [175] investigated a naturally ventilated primary-level classroom in a school situated near an urban road. Forty-three subjects from a single classroom were tested in both summer and winter for IAQ testing. The analysis of the collected data shows that both PM_{10} and $PM_{2.5}$ exceed the NAAQS limit 60% and 27% of the time. respectively. The occupied-classroom PM is found to be higher than the unoccupied classroom due to the resuspension mechanism. The I/O ratio of PM particles decreases with reduced particle size. The high I/O ratio of PM_{10} particles represents the high indoor activity of students in the classroom. A low I/O ratio confirms the permeability of vehicular emissions from the nearby road in the classroom. The relations among PM, meteorological parameters, and student's comfort inside the classroom are significant. Strong seasonal variability is confirmed by determining that the winter season IAQ is poorer than the summer season. However, the authors suggest to work on creating a management strategy for poor IAQ in school classrooms.

Mahima Habil et al. [176] worked on identifying sources of PM and different metal contamination in a naturally ventilated secondary school classroom in Agra. Ten schools (five near the roadside and five in a residential area) were studied for two hundred days considering summer, winter, and monsoon seasons. Schools situated in the residential area had lower PM than non-residential-area schools. Incineration activities, chalk dust, building materials, and paint emissions are the major sources of PM in residential area schools. Similarly, vehicular emissions, windblown and soil-borne dust, and industrial emissions are major sources identified near roadside schools in a non-residential area.

V.S. Chithra et al. [183] monitored PM particle concentrations of various sizes (PM_{10}, $PM_{2.5}$, PM_1) in NV school classrooms for 90 days alongside a roadway and in a forest area in Chennai. Authors found that according to the particle size distribution, coarse particles dominate over fine particles in working hours, and in non-working hours, fine particles dominate over coarse particles in both the schools. However, the roadside school showed 3–4 times higher PM_{10} particle concentrations than the forest-area school due to traffic conditions. $PM_{2.5}$ and PM_1 were also 1.3 to 1.5 times higher in roadside school classrooms. The authors developed an indoor air quality model based on the mass balance method. The developed model accurately predicts the fine PM particles; however, human activities in classrooms promote the sudden resuspension of coarse PM_{10} particles in indoor air, which makes it difficult to predict accurate results for PM_{10} particles.

Sangita Goel et al. [177] tested two chalk types to understand dust generation scenarios during writing and dusting actions on wooden and ceramic boards in the classroom. Extruded calcium carbonate and molded gypsum-type chalks were tested for PM generation and particle size distribution analysis. Calcium carbonate chalk generates low PM in comparison with gypsum chalk. The authors explored that dustless chalks made of gypsum produce more PM and are equally as harmful as other chalks. Children of the 6–11-years age group are found to be the most susceptible group for developing health problems due to the ill effects of poor-quality chalks in the classroom.

Mahima Habil et al. [178] investigated particle and ionic contamination affecting students in school classrooms. Three hundred subjects participated in a questionnaire study with a wide range of students from third class to ninth class. Factors inside and outside the classrooms are equally responsible for poor IAQ. Chalk-dust, wall paint, furniture paint, road dust, vehicular and industrial emissions, and soil dust are the major sources generating PM. Asthma, coughing, dizziness, dry skin, eye irritation, shortness of breath, and frequent headaches were reported as common symptoms in classrooms by the subjects. Poor health is primarily responsible for school absenteeism. Studies show 14 million missed school days per year. The authors suggested simple measures to reduce PM levels in classrooms. Cleanliness, less crowded classes, paved areas, high greenery levels, and the selection of a low-pollution area during school construction are potential measures to increase IAQ in the classroom.

N.L. Sireesha et al. [179] investigated the built environment spatial qualities and their relation to IAQ in thirty secondary schools in Hyderabad. One-hundred and fifty subjects responded to the questionnaire survey. The investigation was conducted in three phases. The author relates IAQ to different activities and recommends that properly designed and maintained schools can potentially reduce IAQ problems. Rohi Jan et al. [180] tested four classrooms and two-hundred and thirty students at an elementary school in Pune for PM and gaseous exposure assessment. PM levels were five times higher than the NAAQS-recommended levels. All gases (O_3, SO_2, NO_2) measured in the classroom were within NAAQS limits except carbon dioxide, which is due to inefficient ventilation and a higher number of students in the classroom. The subjective assessment showed that coughing, a running nose, cold, eye irritation, and fever are the most common symptoms among subjects in classrooms. Similarly, a cold, fever, and a cough were found to be the main reason behind sickness absence.

Akshay Arun Bhalekar et al. [184] investigated outdoor and indoor air quality during the winter season in two schools of Manipal town in Karnataka. The authors monitored PM_{10}, NO_2, SO_2, and CO_2. Temperature, relative humidity, and classroom physical parameters are also considered in this study. The study reveals that there is high CO_2 inside the class as per ASHRAE standards, and by closing doors and windows the PM particles entering the classroom can be controlled, but ventilation is affected. The authors suggested incorporating mechanical ventilation and air-purifying plants in the classrooms to enhance classroom IAQ.

Venu Shree et al. [22] investigated IAQ in eight naturally ventilated primary schools at Hamirpur during the summer. The PM and CO_2 levels inside the classroom were significantly linked to outdoor conditions. A crowded classroom and low relative humidity create the worst indoor air condition for primary school students as they inhale air at lower levels (height) in the classroom. Small children are more vulnerable to eye irritation and airborne disease. The author recommended performing more IAQ studies in primary schools.

S. Jayakumar et al. [181] performed analyses of eleven classrooms of six primary and upper primary schools in Ahmedabad. Two government, two air-conditioned, and two naturally ventilated private schools were considered for the comparison and evaluation of ventilation rates in specific Indian conditions. The steady-state mass balance method was used to determine the ventilation rates in this study. Air-conditioned classrooms had a CO_2 concentration that was too high and ventilation rates too low in comparison with naturally ventilated classrooms. The ventilation rate and CO_2 concentration in AC classrooms did not meet ASHRAE 62.1 [186] and NBC, 2016 [38] standards. NV buildings consume low energy than AC buildings; however, NV classrooms are the least efficient in protecting students from heat and air pollution. Pratima Singh et al. [182] explored the impact of classroom ventilation on student concentration and performance in four schools (two NV and two AC) in South Delhi. Seven hundred and thirty-eight students participated in the performance and concentration test. Winter and non-winter comparisons of the ventilation rate and CO_2 concentration showed that IAQ in winter months is poorer than in non-winter months. The study revealed that the fresh air flow rate and occupancy level of the classroom play a vital role in IAQ. Authors recommend the proper utilization of windows and doors in all types of classrooms with increased break times in order to dilute the accumulated carbon dioxide inside.

All the research conducted in Indian school classrooms mainly focuses on PM, CO_2, and I/O ratios of the PM and CO_2. Only very few studies consider VOCs and other gases. However, only one study [182] tried to determine the effect of IAQ on the performance and concentration of students. One study found the effect of IAQ on sickness absence [180]. The transmission of viruses due to ventilation and airflow patterns inside the classrooms is still unresearched in India.

Thus, there is a lot of scope in the research on IAQ and its factors, and long-term research programs in Indian school classrooms are needed within a centralized open-access database.

4.3. Acoustic Comfort (AcC) in Indian School Classrooms

In school classrooms, generally, occupants have less control over the acoustic environment [187]. Student sitting position, teacher position, adjacent classroom noise, equipment noise, exterior noises, and interior noises can potentially influence student concentration and thus learning [188–190].

N. Subramaniam et al. [150] reviewed thirty years of literature (until 2006) and compared international standards for noise level limits and reverberation time. The authors discussed the Signal-to-Noise Ratio (SNR), Reverberation Time (RT), noise levels, and architectural factors in classroom conditions, mainly focused on enhancing Indian classroom conditions. The authors recommended creating national codes for classroom acoustics and considering sound scattering effects in classrooms. Jolly John et al. [191] examined acoustic parameters, RT, and background noise levels in ten schools in Kerala and compared the results with the Indian national standard NBC recommendation. The values of RT and background noise levels were found to be higher than those recommended in codes. Poorly insulated classrooms and noise intrusion through openings are the main reasons for high background noise. The lack of good-quality absorber materials and less insulation in walls are the main reasons behind higher RT, which affects speech intelligibility in classrooms. The recommended sound insulation of 35 dB was also tested in this study and, very interestingly, the insulation level was very low between classrooms with a value of 28.8 dB.

Naba Kumar Mondal et al. [192] evaluated the vulnerability of school students in classrooms due to roadside vehicular noise. The noise pollution level (LNP), transport noise index, equivalent noise level (L_{eq}), and Noise Climate (NC) were studied to determine the students' vulnerability. The study reported that school's distance from the road was much lower in urban schools (9.4 feet) than rural schools (14.4 feet). The average traffic count was also higher in urban areas than in rural areas. Noise intensity is inversely proportional to the distance from the road. The study reported that not all schools, but rather those that are near the road, are highly affected by noise and thus the teaching–learning process is severely affected. Jolly John et al. [193] investigated the acoustical conditions of schools in the tropical warm humid climate of India. Background noise and RT were tested in Kerala schools. Both of the tested acoustical components were found to be higher than the levels recommended by the National Building Code (NBC) of India. Windows and ventilators were found to be the main contributor to the intrusion of external noises. Low-insulation classroom walls and a lack of absorbing materials are the main reason behind high RT. The study recommended that acoustic deficiencies can be easily reduced by simple treatment to walls and ceilings in classrooms for better acoustic comfort.

Veera Gupta [194] collected, analyzed, and presented policies on acoustics in Indian classrooms. RT, SNR, and the distance between the teacher and student are the main factors that influence the acoustic comfort of the classroom. Different standards are compared with each other. The authors focused on teaching acoustic comfort and its impacts on teachers in their training. The age factor also affects speech perception. The author suggests the idea of performing multidisciplinary studies regarding acoustics in school classrooms in India. Kenneth P. Roy [195] presented certain case studies around the globe for acoustic comfort in classrooms. Speech clarity (i.e., RT), SNR, and the blocking of adjacent noise (insulation) were discussed by various case studies. An Indian case study of a school from Mumbai was presented in this paper. By installing a suspended ceiling, sound absorption of the classroom was increased and brought down the RT of 1.1 s to 0.6 s. The authors focused on increasing classroom acoustic quality through sound-absorptive measures.

Gayathri Sundaravadhanan et al. [196] evaluated the background noise of twenty-three classrooms in four government primary schools. RT was calculated by Sabine's Formula. Teachers' vocals and students' speech perceptions are severely affected by deteriorated acoustic conditions in classrooms especially in the case of younger children. The average noise level was double the recommended noise levels by NBC, 2016. SNR was 10.6 dB and RT was greater than 2.6 s, which is more than three times the prescribed limits. Both occupied and unoccupied cases were not in accordance with the recommended levels. The authors suggested performing more studies in the southern part of India to create a better acoustic environment in school classrooms. Gomathi Saravanan et al. [197] performed the SNR test in thirty-seven classrooms in Chennai. The acoustic comfort of hearing-impaired students was considered in this study. RT was estimated for every classroom in this study. This study finds that the average distance between students and the teacher is 0.98 m and has a range of 0.46 m to 1.57 m. High RT was reported with high background noise conditions and poor SNR in classrooms. The author recommended various measures such as an absorptive ceiling, noise barriers, etc., to modify the classroom for better acoustic conditions.

Almost all studies concluded that the acoustic environment in Indian school classrooms is not up to the mark and the limits of various acoustic parameters are out of the prescribed comfort limits recommended by NBC and other regulations. However, most students never report the problem as they have adapted to those conditions and modified their behavior accordingly. Despite the highly adaptive behavior of Indian students and teachers, it is necessary to provide them a better acoustic environment during their school time. Most of the students and teachers do not know the existing negative impacts on their learning and teaching behavior as they adapted to these conditions and have never compared their performance in other conditions. This gap should be filled quickly as it is degrading the education quality, and every teacher and student must be well informed regarding indoor acoustic quality and comfort and its effects on them.

4.4. Visual Comfort (VC) in Indian School Classrooms

Visual comfort is the least-researched IEQ parameter in the Indian school classroom. Visual comfort is defined as "perceived satisfaction of occupant with lighting condition, levels, and views in occupied space while performing specific tasks" [198]. Research shows that there is a significant influence of the visual environment on speed and accuracy, student health, and psychological behavior [199]. Poor lighting can disrupt the circadian rhythm, influence blood pressure and heart rate, increase mood swings, and reduce performance [200].

Pratima Singh et al. [201] studied classroom illuminance effects on the performance of upper primary school students in the Delhi National Capital Region (NCR). One hundred and twenty students of the 14–15-years age group from two schools (four classrooms) participated in this research. The author selected one green-certified school and one conventional school for comparison. By subjective, objective, and performance tests, authors tried to determine the effect of lighting on students' performance and concentration. They suggested that there is a significant relation between classroom lighting and student performance, but they found no significant correlation between classroom lighting and student health. The green-school students reported excessive lighting whereas non-green school students reported low lighting levels. The green school's students faced certain health symptoms such as blurring vision due to excessive glare, headaches, eye irritation, and strain. On the other hand, students of the non-green school felt tiredness, sleepiness, and excessive stress due to low lighting levels. Overall, green-school students were more satisfied with the visual environment and performed better in performance tests than other school students. They concluded that it is essential to maintain visual comfort inside the classroom for better outcomes.

Pratima Singh et al. [202] performed a cross-sectional study in four schools of Delhi. Seven hundred and thirty-eight students participated in this study. They aimed to explore the relationship between lighting and students' speed and accuracy in the classroom. Subjective and objective assessment along with a d2 test for speed and accuracy were chosen for the research. The authors stated that lighting levels greater than 250 lux and below 500 lux gave the best outcomes. They recommended that providing more natural daylight in the classroom will have the best results.

The National Building Code of India [38] recommended maintaining a minimum lighting level of 200 lux in school classrooms with an upper limit of 500 lux. Excessive artificial lighting can harm students as it contains ultraviolet rays. Similarly, daylight is associated with large and sudden variations in lux levels. Therefore, proper integration of daylight and artificial light is required in Indian school classrooms for maintaining visual comfort with energy efficiency. Ashok Kumar et al. [203] have developed an android application in the Council of Scientific and Industrial Research–Central Building Research Institute (CSIR-CBRI) for integrating artificial lighting with natural daylight for India-specific conditions. The authors are designing buildings using the App that are quite useful at the initial/concept design stage.

5. Recommended Levels of IEQ Parameters according to Existing Indian Standards and Codes

During the systematic review, important data from various public and private Indian standards and codes were collected for an easy understanding of IEQ parameters' suitable levels. The recommended suitable limits of IEQ parameters along with their sub-parameters are jotted down in Table 3 from different India-specific codes and standards.

Table 3. Recommended levels of IEQ parameters and their components specific to Indian school classrooms as per Indian standards.

IEQ Parameters	Sub Parameters (Unit)	Lower Limit	Middle Value	Upper Limit	Standard-Year [Reference]
Indoor Air Quality (IAQ) (including Ventilation)	CO_2 (ppm)	Ambient + 350 [a]	Ambient + 500 [b]	Ambient + 700 [c]	ISHRAE-2019 [158]
	$PM_{2.5}$ (μg/m^3)	<15 [a]	-	<25 [c]	ISHRAE-2019 [158]
		-	<40{Y} <60 {24 h}	-	NAAQS-2009 [185]
	CO (ppm)	<2 [a]	-	<9 [c]	ISHRAE-2019 [158]
		-	<2 mg/m^3 {8 h} <4 mg/m^3 {1 h}	-	NAAQS-2009 [185]
		-	<10 mg/m^3	-	GRIHA-2014 [204]
	TVOC (μg/m^3)	<200 [a]	<400	<500 [c]	ISHRAE-2019 [158]
	PM_{10} (μg/m^3)	<50 [a]	-	<100 [c]	ISHRAE-2019 [158]
		-	<60 {Y} <100 {24 h}	-	NAAQS-2009 [185]
		-	<60 {Y} <150 {STL}	-	NBC-2016 [38]
		-	< 20	-	GRIHA-2014 [204]
	CH_2O (μg/m^3)	<30 [a]	-	<100 [b]	ISHRAE-2019 [158]
	SO_2 (μg/m^3)	<40 [a]	-	<80 [b]	ISHRAE-2019 [158]
		-	<80 {Y} <400 {STL}	-	NBC-2016 [38]
		-	<50 {Y} <80 {24 h}	-	NAAQS-2009 [185]
	NO_2 (μg/m^3)	<40 [a]	-	<80 [b]	ISHRAE-2019 [158]
		-	<200 {Y} <500 {STL}	-	NBC-2016 [38]
		-	<40 {Y} <80 {24 h}	-	NAAQS-2009 [185]
	O_3 (μg/m^3)	<50 [a]	-	<100 [b]	ISHRAE-2019 [158]
		-	<60 {24 h} <100 {8 h} <180 {1 h}	-	NAAQS-2009 [185]
	Lead (Pb) (μg/m^3)	-	<0.5 {Y} <1 {24 h}	-	NAAQS-2009 [185]
	NH_3 (μg/m^3)	-	<100 {Y} <400 {24 h}	-	NAAQS-2009 [185]
	Benzene (μg/m^3)	-	5 {Y}	-	NAAQS-2009 [185]
	Arsenic (ng/m^3)	-	<6 {Y}	-	NAAQS-2009 [185]
	Benzo(a)pyrene (ng/m^3)	-	<1 {Y}	-	NAAQS-2009 [185]
	Nickel (ng/m^3)	-	<20	-	NAAQS-2009 [185]
	Ventilation rate per person (l/s.person)	6.7	-	8.6	NBC-2016 [38]
	Ventilation rate (Cfm/Sqft)	5.0	7.5	10.0	IGBC-2015 [205]
	Ventilation (Air Changes per Hours)	-	5–7	-	NBC-2016 [38]
		-	3–6	-	SP-41 1987 [163]
Acoustic Comfort (AcC)	Indoor Noise Level (dB)	35	-	40	ISHRAE-2019 [158]
		45	-	50	IS 1950–1962 [160]
		40	-	45	GRIHA-2014 [204]
		40	-	45	NBC-2016 [38]
	RT (Second)	0.6	0.8	1.0	ISHRAE-2019 [158]
		0.6	-	1.1	NBC-2016 [38]
	Speech Transmission Index	-	0.5–0.6	-	ISHRAE-2019 [158]

Table 3. *Cont.*

IEQ Parameters	Sub Parameters (Unit)	Lower Limit	Middle Value	Upper Limit	Standard-Year [Reference]
Thermal Comfort (TC)	Operative Temperature (°C)	25	27.5	30	SP-41 1987 [163]
		19 [d]		34 [d]	SP-41 1987 [163]
		-	<33	-	GRIHA-2014 [204]
		25	27.5	30	NBC-2016 [38]
		19 [d]	-	34 [d]	NBC-2016 [38]
		22.0 ± 3.0	-	24.5 ± 2.5	ISHRAE-2019 [158]
	Relative Humidity (%)	30	-	70	SP-41 1987 [163]
		-	<70	-	GRIHA-2014 [204]
		30	-	70	ISHRAE-2019 [158]
	Vertical Air Temperature Difference (°C)	-	4	-	ISHRAE-2019 [158]
Visual Comfort (VC)	Illuminance (lux)	150	200	300	SP-41 1987 [163]
		150	-	300	IS-7942, 1976 [206]
		150	-	300	IS-8827 1978 [207]
		150	-	300	IGBC-2015 [205]
		200	300	500	NBC-2016 [38]
		-	300	-	GRIHA-2014 [204]
		-	300	-	ISHRAE-2019 [158]
	Limiting Glare Index	-	16	-	SP-41 1987 [163]
		-	3	-	NBC-2016 [38]
	Daylight Factor (1DF = 80 lux)	-	2.5	-	IGBC-2015 [205]
		1.9	-	3.8	IS-7942, 1976 [206]
		1.9	-	3.8	SP-41 1987 [163]

[a] Maximum limit for Class A type spaces having 90% occupant satisfaction rate. [b] Maximum limit for Class B type spaces having 80% occupant satisfaction rate. [c] Maximum limit for Class C type spaces having less than 80% occupant satisfaction rate. [d] Tolerable thermal environment limits, thermal comfort lies within this temperature band. {Y} means yearly arithmetic mean of minimum 104 readings. The readings must be taken twice in a week at a uniform time interval between 24 h. {24 h}/{8 h}/{1 h} means 24-hourly, 8-hourly, and one-hourly monitored values sequentially. {STL} means short-term level, which cannot exceed once a year.

6. Discussion

6.1. Study Types and Publication Trends

After a critical search of the available literature focused on IEQ parameters in Indian school classrooms, only thirty-seven articles were traced in the last fifteen years. Twenty-nine articles were based on a real-time research study conducted on one or more IEQ parameters in the Indian school classroom. Furthermore, eight review articles focused on Indian school classrooms were considered for the formation of this article. Figure 10 represents an increased research trend (approximately six times) in school classroom IEQ with frequent studies after the year 2010.

Table 4 presents the analysis of different IEQ parameter studies with Indian climatic zones. The analysis determined that IAQ in the Indian school classroom is the most-researched parameter, being present in seventeen studies. This is followed by AcC with eight studies. Similarly, with six studies, TC remains at third position among the four parameters. Visual comfort, with only two studies, is the least-researched parameter during the fifteen-year span in the Indian school classroom.

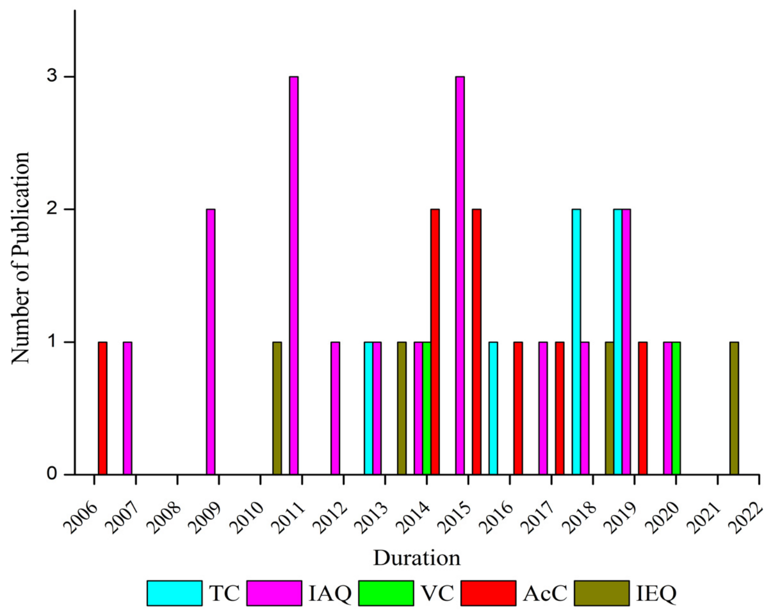

Figure 10. IEQ parameters publications specific to Indian school classrooms in the last fifteen years (July 2006–March 2021).

Table 4. Distribution of studies based on IEQ parameters and their reported Indian climatic zone.

IEQ Parameter	Climate Typology						Total Studies
	Hot-Dry	Warm-Humid	Temperate	Cold	Composite	Mixed	
IAQ	01	04	-	-	12	-	17
AcC	-	06	-	-	-	02	08
TC	-	-	-	-	02	04	06
VC	-	-	-	-	02	-	02
IEQ	-	01	-	-	01	02	04
Total	01	11	-	-	17	08	37

Seventeen studies were performed in the composite climate of India, making it the most-researched climatic zone for the study of IEQ parameters in the school classroom. Eleven studies were performed in the warm–humid climate. One study was performed in a hot–dry climate. The temperate and cold climates of India have been excluded to date from IEQ parameter studies in school classrooms. Eight review articles were based on mixed climate conditions.

Figure 11 indicates that IEQ parameter studies in Indian school classrooms are strewn and inadequate. The absence of connection among different IEQ parameters in classroom studies suggests that unorganized research was carried out in the past. In India, pre-primary schools (now foundation) are neglected from IEQ studies and only one study [22] is performed in class 1. Seven studies in preparatory-level schools, five studies in middle-level schools, and thirteen studies in secondary-level schools were performed during the last fifteen years in the country. Figure 12 depicts the strewn geographical spread of different IEQ parameter studies in Indian school classrooms.

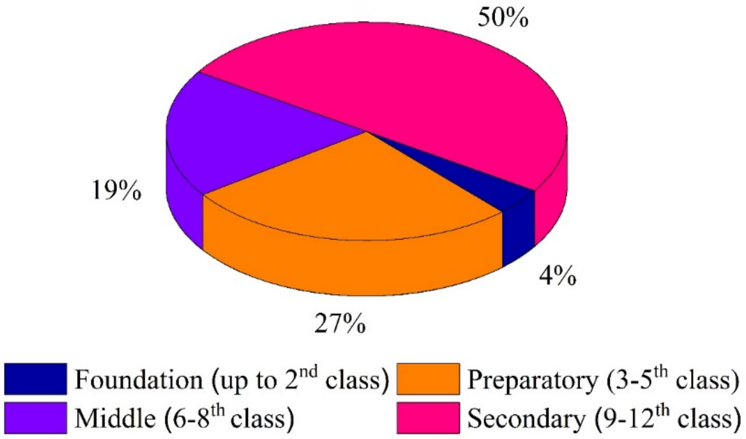

Figure 11. IEQ parameter studies conducted at different schooling levels in India.

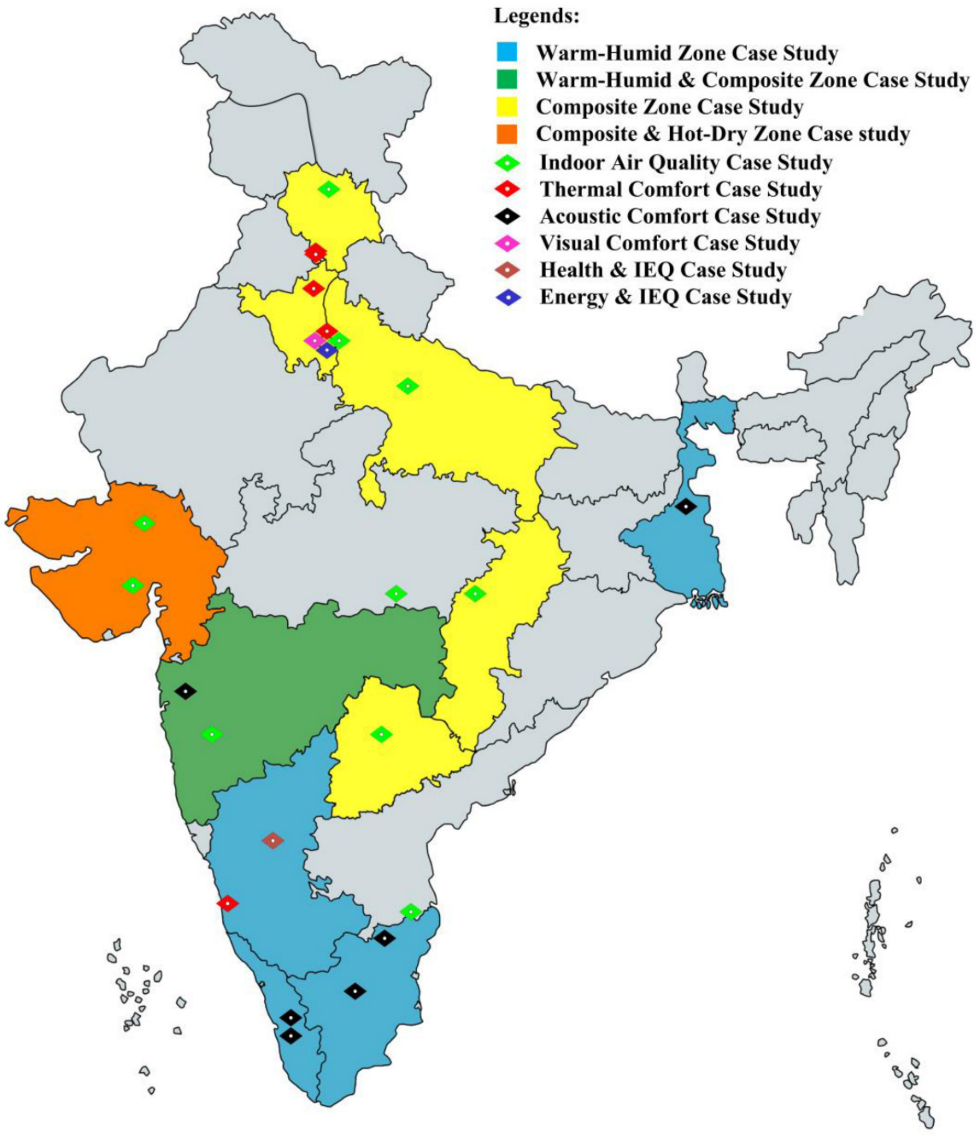

Figure 12. Geographical distribution of studies on IEQ parameters in Indian school classrooms.

6.2. Existing Gaps and Deficiencies

This review explored the current status of IEQ in Indian school classrooms by systematically reviewing existing studies for India-specific conditions. Fewer real-time research studies were reported throughout India. More than 90% (to be precise, 92.5%) of existing IEQ parameter studies in India were performed in naturally ventilated school classrooms. To date, only two real-time studies [181,182] (7.5% of total) consider air-conditioned classrooms for their research, exploring a huge gap among different classroom operative modes. Further, only one study [208] considers the relationship between IEQ and energy consumption in Indian school buildings. Only one study [201] tested IEQ parameters in Green School (GS) classrooms. However, the energy component is not considered in the GS study. Despite having the most extreme conditions in cold and hot–dry climates, Indian school classrooms in these climatic zones are overlooked for IEQ parameter research.

There is no study on testing IEQ parameters in the pre-primary classroom and only one study [22] on IAQ in class 1. There is no Indian classroom-specific model for any of the IEQ parameters that is well accepted. None of the studies consider the variation among the students' social, cultural, and economic status. During various tests, the Hawthorne effect is neglected, which can potentially influence study results as subjects behave differently when they know they are being observed. It is hard to compare studies with one another as conditions and methods are different. Even in a single study, classroom conditions such as dimensions, orientation, furniture setup, room openings, lighting conditions, student strength, testing time, exterior conditions, etc., vary significantly. Thus, it is difficult to produce firm comparisons.

Only a few studies [172,176,180,192,201,209,210] tried to test existing sick building syndrome conditions in Indian school classrooms, which were not significant. The relation among IEQ parameters with students' and teachers' health is not deeply researched until now in India. To date, no study tested digital classrooms or hybrid classrooms in Indian schools for their indoor environmental conditions nor the impact of advanced technologies on classroom IEQ. Further, there are fewer data available to standardize the testing procedure, thus no specific public IEQ code or standard has been present in this country until now. IEQ is excluded from the National Education Policy (NEP) 2020, which should be part of the new NEP 2020. The inadequate awareness of the Indian public (students, teachers, staff, parents, and other stakeholders) regarding IEQ in school classrooms and other buildings is a huge gap that can be filled by proper training and information. Multifactor studies on IEQ are have not been performed to date in any Indian schools. Thus, it is hard to explore the combined impact of IEQ parameters on students during any ongoing session. Performance tests were considered within some studies [182,201,202] but most of the studies neglected to assess students' performance while measuring IEQ parameters in the classroom. Therefore, there is a primary need to carry out further research on the effect of all IEQ parameters simultaneously on students' as well as teachers' comfort and health in Indian classrooms along with performance or efficiency tests of students and teachers. Secondly, there is a need to develop an open-access, centralized database for the country, and lastly, more research on factors that can potentially affect IEQ in Indian schools should be conducted.

6.3. Factors Influencing Future Research on IEQ in Indian School Classrooms

The COVID-19 pandemic has created a terrible situation among researchers globally, but it is now time to review the health and wellbeing aspects again in all types of buildings [211–214]. The density of occupants is much higher in school classrooms than rooms in other types of buildings [215,216]. This makes school classrooms more prone to infections and communicable diseases [217–219]. Research proves that the SARS-CoV-2 virus can be transmitted through the air and can remain in the air as a micro-droplet or nuclei for hours and can travel large distances [220,221]. Therefore, it is dangerous to continue studies in AC classrooms as the air recirculation rate is higher than in NV classrooms and it is most likely that the SARS-CoV-2 virus can infect classroom students [222–224]. Similarly, in

AC classrooms, due to stagnant air inside, the possibility of the rapid spread of infection increases due to the presence of an indoor infection source [225–229]. In general, there are two routes of infection spread in closed spaces. First, aerosol droplets generated by the infected person are directly inhaled by the exposed person. This occurs when the distance between the infected person and the exposed person is less than 1.5 m. Second, aerosols generated by the infected person's activities are mixed with the room air and airflow; the droplet nuclei travel and enter the system of the exposed person. This occurs over large distances, generally greater than 1.5–2.0 m [230–233]. Figure 13 represents the exposure distance effect on infection probability after inhaling the contaminated air where viral shedding occurs due to the infected person's activities (S) such as exhaling, speaking, singing, shouting, sneezing, coughing, or yawning, etc. [234–236]. Individual 1 stands near the infected person (S) in highly concentrated infectious air as shown below on the right-hand side, whereas infection through airborne particle inhalation is shown on the left-hand side of the image.

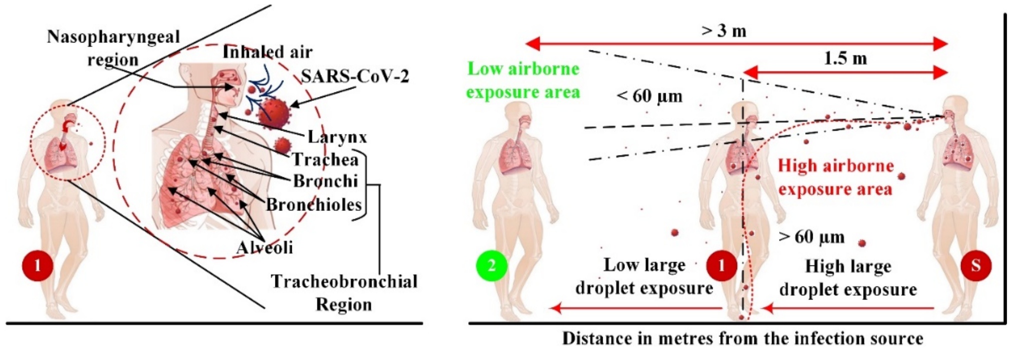

Figure 13. SARS-CoV-2 transmission by short-range close contact and long-range contact.

The respiration rate of children is higher, and with an increase in age the respiration rate decreases [237]; the respiration rate of different age groups is presented in Table 5. In children, the respiration rate is higher; however, the volume inhaled is low as their organs are small and still in the development stage [238]. Due to the fast respiratory cycle, they are more prone to the virus infection suspended in the air as their breathing cycle is twice that of adults [239,240]. Additionally, small children's highly active nature cause dyspnea resulting in abnormal breathing. Emotional state, physical fitness, internal temperature, and health status are the four factors that affect the respiration rate of any individual. During low metabolic activities such as sleeping, etc., the respiratory rate is low, and for high metabolic activities such as exercise, sports, and heavy work, etc., the respiratory rate is higher.

Table 5. Age-specific respiratory rate at rest.

Category	Age	Respiratory Rate [Breaths per Minute (bpm)]
Newborn baby	0–1 month	40–60 bpm
Infant	1 month–1 year	35–40 bpm
Toddler	1–3 years	25–30 bpm
Preschooler	3–6 years	21–23 bpm
School-age	6–12 years	19–21 bpm
Adolescent	12–19 years	16–18 bpm

According to a comment report [241] available on 'The Lancet', it is quite evident that COVID-19 is an airborne disease and SARS-CoV-2 is an airborne pathogen. This report was prepared by six experts of the US, UK, and Canada and it advocates in the favor of a hypothesis based on the aerial transmission of the SARS-CoV-2 virus. The authors suggest that aerosols are more dangerous than respiratory droplets as they are smaller in size and contain more viral concentrations in them. The other fact is that due to low gravitational impact and having a smaller size, these aerosols can travel longer distances than large droplets. Classrooms have more physical activity resulting in more resuspension of fine particles creating worse conditions for students' and teachers' health. Ten points that are presented in this report as proof include (i) super-spreading events of COVID-19, (ii) long-range transmissions, (iii) asymptomatic or pre-symptomatic transmissions, (iv) higher indoor transmission than outdoor, (v) nosocomial infections after using PPE kits in hospitals, (vi) viable SARS-CoV-2 virus detection in the air for 3 h, (vii) SARS-CoV-2 identification over the air filters and building ducts, (viii) animal experiments show transmission through ducts by means of air, (ix) the unavailability of any scientific study to oppose or refuse the hypothesis of airborne transmission of COVID-19 virus, and (x) limited evidence to support other dominant routes of transmission (respiratory droplet or fomite). A comparison of various possible IAQ-enhancing solutions for different types of buildings in the COVID-19 pandemic situation was conducted in a previous study [242]. The study concluded after a critical assessment of various indoor and outdoor air-related solutions that more than one solution among different solutions will help in reducing the infection spread probability. However, presently, there is no scientific technique or single solution available that can completely safeguard occupants from SARS-CoV-2 and similar viruses.

As per the latest information provided on the UNESCO [23] website, currently, 60% of the world's students are severely affected by the lockdown conditions due to the COVID-19 pandemic. The school closure duration surpasses fifty weeks in India and the total affected learners are around 320,713,810, which is approximately 25% of the current national population [23]. Health and protection risks arise in continuing conventional education process in schools without safety measures [243]. As a developing nation, household structure, resources, and socio-economic conditions severely affect Indian students [244,245]. Personal safety measures are not sufficient when dealing with densely populated classrooms [246,247]. The primary health concern among school administrations is to prevent COVID-19 from spreading when students resume their studies, otherwise the spread of the virus i.e., SARS-CoV-2 will increase rapidly again in India. Figure 14 illustrates the probable infection spread cycle in the community via schools due to classroom teaching, where red shows infected people and green represents healthy people.

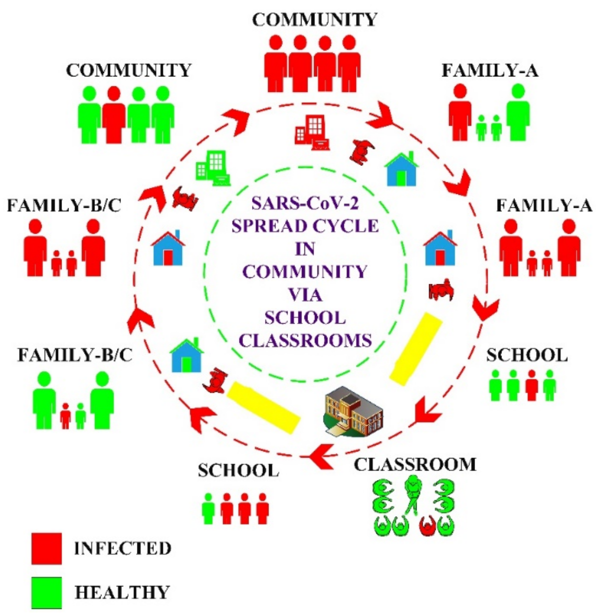

Figure 14. COVID-19 spread cycle between community and school due to low safety measures in schools and community.

Due to disrupted routines, less outdoor activity, confined indoor spaces, poor eating habits, stress, and anxiety increases the probability of obesity among students [248–252]. Obesity is a disorder in the human body due to the accumulation of excess fat, which is resultant of sedentary behavior [253–257]. Due to the lockdown and the use of more smart digital appliances, less physical work is achieved by students [258]. Good IEQ conditions in the classroom can motivate children to actively participate in different activities other than reading and writing activities, such as yoga, sports, group play, etc., which can potentially help them to become physically fit [259,260]. Rapidly changing teaching techniques and tools are also a considerable factor for determining and monitoring IEQ in intelligent [261] and digitalized classrooms [262–264]. GS buildings are the future of sustainable school buildings in India. Daylight autonomy, solar energy, and smart classrooms will affect the research scenario and increase the demand for good IEQ in Indian school classrooms [265,266]. Further, the demand for energy-efficient systems in school buildings may also increase to achieve more than one sustainability goal. After the implementation of NEP, the digital revolution in the education sector and Information and Communication Techniques (ICT) will possibly gain more attention [267,268]. Rapidly advancing technologies such as Artificial Intelligence (AI) [269–274], Internet of Things (IoT) [275–283], Big Data [284–287], Robotics [288–291], and Cloud Techniques [283,292–294] must be utilized properly and effectively with IEQ research to develop innovative tech-gazettes for monitoring, sampling, modeling, data accumulation, analyzing, and providing a safe and comfortable Human–Building Interaction (HBI) [295]. Moreover, setting up a centralized, open-access online database in India will enhance the quality and impact of research related to IEQ parameters in the future.

6.4. Advances in IEQ with Artificial Intelligence (AI)

Artificial intelligence works like human thinking to solve complex problems that the human brain cannot handle or are too tough to solve [296–298]. The introduction of AI technology decreases the burden of manual calculations. The natural brain is only able to compute calculations at a certain level, but computational technological methods solve and process thousands of calculations within seconds at a rate impossible for the average human brain [299–301]. The foundation of AI is based on several learning techniques such as machine learning, deep learning, and reinforcement learning, etc. AI is applied in several areas such as policymaking, energy efficiency, prediction, planning, economy, management, and optimization. Figure 15 shows the application of AI in IEQ.

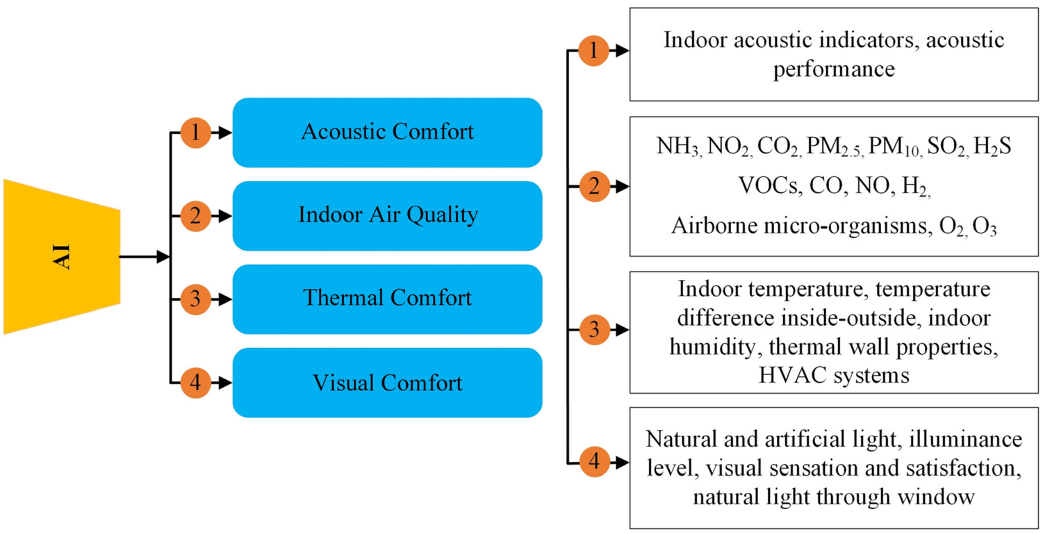

Figure 15. AI in IEQ.

Particularly in the area of IEQ, artificial intelligence plays an important role in the prediction of energy consumption and model generation for TC, IAQ, VC, and AcC. The details of the applications of AI in IEQ are as follows:

6.4.1. AI in TC

The role of AI in TC summarized by various researchers from the past few years are tabulated in Table 6 [302–313]. The artificial Neural Network (ANN) model was prepared by Moon et al. [302] to predict the temperature inside a residential building during maximum occupancy. The maximum accuracy of this model was 99.99% in the prediction of indoor TC, and the reduction in the energy was also considered in this study. Mba et al., Irshad et al., Kim, and Thongkhome and Dejdumrong [303,308–310] also used the ANN model to predict thermal comfort by using input parameters such as indoor temperature, indoor humidity, wind speed, metabolic rate, and clothing, etc. A few researchers used other AI techniques such as Reinforcement Learning, Fuzzy logic, Multilayer Perception (MLP), Random Forest (RF), Deep-reinforcement leaning (FNN), K-Neighbors Regression (KNR), Support Vector Regression (SVR), Tree Regression (TR), Linear Regression (LR), Decision Tree, Naïve Bayes, Support Vector Machine (SVM), and Deep ANN (DANN).

Table 6. Summary of AI research studies in TC.

Author [Ref]	Year	Building Type	Method	TC Parameter	Input/Output	Results
Moon et al. [302]	2016	Residential	ANN	Indoor temperature, temperature difference and outdoor temperature	TEMPIN, TEMPOUT, ΔTEMPDIF	R^2 = 0.9999
Mba et al. [303]	2016	Experimental Building	ANN	Indoor temperature (IT), indoor humidity (IH)	Indoor and outdoor temperature, Sunshine and relative humidity monthly data	R = 0.9850 (IT) R = 0.9853 (IH)
Valladares et al. [304]	2019	Classroom and Laboratory	Reinforcement Learning	Thermal comfort and indoor air control	Temperature, humidity and CO_2, Specifications of air condition unit and ventilation fan	PMV values within range −0.1 to +0.07 and 10% reduction in CO_2 values while saving 4–5% energy
Zhang et al. [305]	2021	Office Building	Fuzzy logic	Indoor temperature and thermal comfort	Indoor air temperature, indoor air relative humidity, outdoor air temperature, outdoor air relative humidity, CO_2 concentration, Skin temperature and heart rate	Daily energy consumption = 20.07% (point-based control) Daily energy consumption = 10.73% (feedback-based control)
Bienvenido-Huertas et al. [306]	2020	Household Building	MLP, RF	Thermal properties of wall	Tint, max(Tint), min(Tint), Text, max(Text), min(Text), q, max)(q), min(q), thickness, time, period	RF Model is good to estimate the periodic thermal variables
Gao et al. [307]	2020	Normal Building	Deep reinforcement learning (FNN)	Energy efficient thermal comfort	Temperature, Humidity, Radiant temperature, Air Speed, Metabolic rate, Clothing insulation	Improved thermal comfort by 13.6% and reduce energy consumption of HVAC = 4.31%
Irshad et al. [308]	2020	Office Building	ANN	Predication of thermal comfort with installed AC	Air temperature, relative humidity, globe temperature, wind speed, metabolic rate, and clothing	MSE = 5.1789
Kim [309]	2020	Office Building	ANN, DNN	HVAC system optimization for thermal comfort	T_z^t = zone z at time t is affected by the power inputs, Pt of the HVAC system and the thermal conditions, Et of a multi-zone building during the time from $t - \tau$ to t.	NMSEs = 0.9999
Thongkhome & Dejdumrong [310]	2020	House Building	ANN	Thermal comfort environmental predication	Temperature and relative humidity	Accuracy = 99.54%

Table 6. *Cont.*

Author [Ref]	Year	Building Type	Method	TC Parameter	Input/Output	Results
Zhou et al. [311]	2019	Office Building	Model-Driven learning {K-Neighbors Regression (KNR), Support Vector Regression (SVR), Tree Regression (TR), and Linear Regression (LR)}.	Dynamic thermal comfort	Temperature, air velocity and humidity	PMV model predicting values
Rehman et al. [312]	2020	Commercial building	Decision Tree, Naïve Bayes, SVM, MLP, and DANN	Personalized comfort	Temperature and humidity	Highest accuracy = 84.35%
Luo et al. [313]	2018	Normal room	-	Metabolic rate and thermal comfort	Temperature, humidity, BMI, Sex, age pregnancy and menopause status	-

6.4.2. AI in IAQ

AI methodologies have been used in IAQ for different types of buildings and are summarized in Table 7 [314–326]. Most researchers used CO_2, particulate matter, VOCs, and NO_X as input parameters to predict and optimize the IAQ parameters in different indoor scenarios. The various AI techniques used are the Adaptive Network-based Fuzzy Interface System (ANFIS), Backward Progression (BP), Multiple Linear Regression Method (MLRM), ANN, Gated Recurrent Unit (GRU), Long Short-Term Memory (LSTM), MLP-NN, Deep RNN, Decision Tree Regression Method, Extended Fractional-order Kalman Filter, Machine learning-based non-parametric forecasting, Multiple Linear Regression, Non-Linear ANN, Time Slicer Method, PAD method, and Autoregressive Integrated Moving Average (ARIMA). The work in this direction is growing rapidly.

Table 7. Summary of AI research studies in IAQ.

Author [Ref]	Year	Building Type	Method	IAQ Parameter	Input/Output	Results
Xie et al. [314]	2017	Commercial	ANFIS, BP, MLRM	NH_3	Pit NH_3 concentration, Room temperature, Pit temperature, Room humidity, Pit humidity, Pig activities, Pit fan-E speed, Pit fan-W speed, Room fan 14″, Room fan 20″, and Pig manure	ANFIS, BP and MLRM results in summer and winter MSE = 0.0047 and 0.002, R^2 = 0.6483 and 0.6351; MSE = 0.0137 and 0.0042, R^2 = 0.6066 and 0.5543; MSE = 0.0174 and 0.0660, R^2 = 0.5957 and 0.702.
Challoner et al. [315]	2015	Office	ANN	NO_2, $PM_{2.5}$	Time of day, barometer level pressure (hPa), sea level pressure (hPa), temperature (°C), relative humidity (%), wind speed (knots), wind direction (knots), Pasquill atmospheric stability class, global solar radiation (j. cm^2) and outdoor pollutant concentrations	Location 1, 2 and 3: For NO_2, R^2 = 0.854, 0.870, 0.829; For $PM_{2.5}$, R^2 = 0.711, 0.760, 0.770.
Ahn et al. [316]	2017	Office	Gated recurrent unit LSTM	$PM_{2.5}$, CO_2, VOCs	CO_2, VOC, humidity, temperature, light amount, and fine dust	Prediction Accuracy: GRU = 84.69 LSTM = 70.13
Adeleke et al. [317]	2017	Residential	MLP NN	$PM_{2.5}$	Indoor $PM_{2.5}$ concentration	Precision up to 0.86, Sensitivity of up to 0.85.
Liu et al. [318]	2018	Residential	ANN	CO_2, $PM_{2.5}$, and PM_{10}	Indoor $PM_{2.5}$ and PM_{10} concentration, indoor temperature, relative humidity, indoor CO_2 concentration	For $PM_{2.5}$, R^2 = 0.97 For PM_{10}, R^2 = 0.91 For Fungi, R^2 = 0.68
Loy-Benitez et al. [319]	2019	Waiting rooms	Deep RNN	$PM_{2.5}$, PM_{10}, CO_2, NO_2, CO, NO	x_t (current input)	RMSE = 29.73 μg/m^3, MAPE = 29.52%, RMSE = 30.99 μg/m^3, MAPE = 31.10%
Vanus et al. [320]	2016	Residential	Decision tree regression method	CO_2	Internal and external temperature, internal RH, date and time	RMSE = 46.25 ppm

Table 7. *Cont.*

Author [Ref]	Year	Building Type	Method	IAQ Parameter	Input/Output	Results
Ha et al. [321]	2020	Office	Extended fractional-order Kalman filter	H_2, NH_3, ethanol, H_2S, toluene, CO, CO_2, O_2	CO_2, CO, O_2, H_2, NH_3, ethanol, H_2S, toluene, temperature, humidity	MSE = 0.8612, 0.39993, 0.7082, 0.5122, 0.6103, 0.6761, 0.4738, 0.4262, 0.3601, 0.3007
Elhariri et al. [322]	2019	Office	Gated recurrent unit	CO_2	Humidity, temperature and CO_2	RMSE = 4.0474125
Fang et al. [323]	2016	Residential	Machine learning-based non-parametric forecasting	$PM_{2.5}$, VOC	Humidity, temperature, VOCs, $PM_{2.5}$	NRMSD = 7.5%
Maag et al. [324]	2018	Office and residential	Multiple linear regression, non-linear ANN	O_3, CO_2, VOC	O_3, temperature, VOC	For O_3: RMSE = 7.4 ppb, R^2 = 0.78 For CO_2: RMSE = 8.1 ppb, R^2 = 0.88
Schwee et al. [325]	2019	Office	Time slicer method, PAD method	CO_2	CO_2, temperature	PAD method has more accuracy than time slicer method
Xiahou et al. [326]	2019	Residential	ARIMA	$PM_{2.5}$, PM_{10}, CO_2, tVOC, formaldehyde	$PM_{2.5}$, PM_{10}, temperature, CO_2, tVOC, formaldehyde	Mean prediction error = 0 The model have high prediction accuracy

6.4.3. AI in VC

The use of artificial intelligence in VC is tabulated in Table 8 [327–332]. The input parameters used by various researchers are the orientation of the sun, illuminance levels, glare level, opening of windows, and weather conditions, etc. The most-used computational techniques in various studies are Fuzzy rule based, the Multi-Objective Genetic Algorithm (MOGA), Multi-Objective Non-Dominated Sorting Genetic Algorithm (NSGA-II), Genetic Algorithm (GA), Linear Regression (LR), and Support Vector Machine (SVM).

Table 8. Summary of AI research studies in VC.

Author [Ref]	Year	Building Type	Method	VC Parameter	Input/Output	Results
Rodriguez et al. [327]	2015	Office	Fuzzy rule base	Natural and artificial Light	Sun position, illuminance level, glare	Maintain visual comfort with decreasing the use of artificial light.
Penacchio et al. [328]	2015	Residential, commercial, office and industrial	MOGA	Visual discomfort	Spatial structure in scenes from nature, and sensitivity of the human visual system, visual discomfort	R^2 = 0.810
Delgarm et al. [329]	2016	Office	Multi-Objective Non-Dominated Sorting Genetic Algorithm (NSGA-II)	Visual comfort	Building orientation, Window length, Window width, Overhang tilt angle, Overhang depth	Final optimum configuration leads to 23.8–42.2% decrease in the annual total building energy consumption.
Kim et al. [330]	2016	Office	GA	Natural light through window-by-window size	Azimuth angle, Outdoor illuminance	GA optimized model saved 11.7% energy.
Cen et al. [331]	2019	Residential, Office	LR, SVM	Illuminance level	Eye pupil size, illuminance levels, visual sensation and visual satisfaction	Accuracy = 0.7086 for visual sensation, and Accuracy = 0.65467 for visual satisfaction
Kar et al. [332]	2019	Office	Python-based method	Visual comfort	Consumed energy for maintain comfortable visual environment	72% reduction in energy consumption with maintaining good visual environment

6.4.4. AI in AcC

AI methodologies have been used in AcC for different types of buildings and are summarized in Table 9 [333–335]. Most researchers used various acoustic comfort parameters as inputs to predict and optimize the AcC in different indoor scenarios. The various AI techniques used are ANN, Backward Progression (BP), the Feed Forward Network (FFN), Support Vector Machine (SVM), Random Forest (RF), Gradient-Boosting Decision Tree (GBDT), and Multi-Objective Non-Dominated Sorting Genetic Algorithm (NSGA-II).

Table 9. Summary of AI research studies in AcC.

Author [Ref]	Year	Building Type	Method	AcC Parameter	Input/Output	Results
Zhong et al. [333]	2019	Institutional Building	ANN, BP, FFN	Acoustic comfort	Temperature, noise, relative humidity and CO_2	R^2 = 0.469–0.928
Yeh and Tsay [334]	2021	Institutional Building	SVM, RF, GBDT and ANN	Indoor Acoustic Indicators	Details of Ceiling and wall materials	ANN shows good results (Except reverberation time)
Khan and Bhattacharjee [335]	2021	Normal Building	NSGA-II	Acoustic Performance	Total floor area, climatic zone, number of storeys, and building envelope parameters	Results changes with wall and roof material thickness

6.5. IEQ Demands in Indian School Classrooms

The following are the twelve remarks for future research studies and actions that are drawn from reviewing the existing Indian studies to answer the challenge of IEQ:

- Studies on IEQ parameters in Indian school classrooms are inadequate, unorganized, and unevenly geographically scattered. Therefore, more real-time subjective and objective studies are needed in India along with effective policies and well-drafted plans to implement and enhance IEQ in school classrooms. There are various inconsistencies in methods used by Indian researchers. Therefore, there is a need to standardize the testing methods. This will finally help in creating India-specific public IEQ standards for school buildings as there are no public codes for IEQ in school classrooms to date.
- There is a huge difference among various IEQ parameter studies. VC is the least-researched parameter in Indian schools. Therefore, maximum IEQ parameters must be considered during future objective and subjective surveys. Age variation also impacts the results, hence education-level-specific studies should be conducted and all the levels should receive proper attention.
- Interdisciplinary quality research based on the scientific approach is required on IEQ in Indian school buildings. The energy and health domain should also be studied and included in research along with IEQ performance in Indian school classrooms.
- Occupants' social, economic, and cultural aspects should be considered properly for more accuracy in results and accurate future predictions as all these aspects vary largely among the student population in any class.
- The Hawthorne effect must be considered during real-time research execution in school classrooms so that the results have less deviation due to psychological variations among subjects.
- Different authors adopt different methods for assessing the quality of the indoor environment in school classrooms, so it is hard to compare the results of different studies as outcomes vary significantly both in quantitative and qualitative terms. Therefore, more empirical and data-driven research is essential for advancing classroom IEQ research.
- Effective techniques for merging natural daylight with artificial lighting, effective ventilation techniques, energy-efficient conditioning, and proper design interventions for the acoustic environment are some steps that must be taken to increase IEQ in the Indian school classroom.
- As none of the studies tried to determine the interrelation between different parameters of indoor environmental quality in school buildings, it is very difficult to comment on the combined effect of IEQ parameters on students and teachers in Indian school classrooms. No real-time study considers all IEQ parameters in Indian school classrooms. Therefore, there is a need to study the interrelation and combined effect of IEQ.
- As very scarce studies in the Indian climatic zones are carried out on single or multiple IEQ parameters in the school classroom, more studies are needed in the future for better understanding and climate-wise comparison.

- Overcrowding must be avoided in classrooms with increased natural ventilation, as stagnant air can create serious health conditions with spreading COVID-19 at a faster rate. The recirculation of air must not be executed in school buildings. Openings in the classrooms must be well supported with such a system/technology that can destroy viruses suspended in the air. If possible, school authorities can temporarily think about open-air classrooms with precautions.
- AI, IoT, Big Data, Robotics, and Cloud-like advanced technologies and techniques should be used to innovate and create smart, efficient, technical gazettes as well as applications related to IEQ and HBI. Additionally, advanced techniques and technology should be developed to face COVID-19-like situations in the present and future.
- Increasing air pollution and other factors that have higher probabilities of affecting IEQ in buildings should be further explored, and it is essential to research these factors and their impact on IEQ conditions so that existing and future codes and standard show less deviation from the real-time indoor comfort conditions. Likewise, air-conditioned school classrooms and other air-conditioned spaces in schools need more research related to their indoor environment. Additionally, AQI should be updated and include biological factors along with chemical and particulate matter.

7. Conclusions and Future Direction

Research on IEQ parameters has been blooming among Indian researchers in the last decade. However, very interestingly, school buildings still leave much to explore regarding their indoor environmental conditions. Requirements for good IEQ in Indian school classrooms are the primary concern nowadays, which can further be given more attention due to the pandemic situation. However, research in this area is inadequate and unevenly scattered geographically throughout India. Indian school classrooms are bleak and in dire need of energy-efficient modifications with good IEQ for better teaching and learning outcomes. The performance of students, as well as teachers, is another area of research directly linked to IEQ and the indoor comfort domain. The current state of the art of Indian IEQ conditions in schools indicates that a standardized method is essential for reliable studies and results. COVID-19 is the turning point in the direction of the health and wellbeing of students in classrooms. Research in this area will have long-term outcomes that help in reducing various communicable and respiratory diseases along with the overall development of the nation. However, the seed of IEQ research in India is well sown by researchers and academicians. It is now for stakeholders to see that the tree flourishes. This paper has presented a systematic review of the current status of studies conducted on IEQ parameters in Indian school classrooms to explore the difficult 'IEQ Conundrum'. Eventually, more studies that focus on IEQ assessment in Indian school classroom/s are required to eliminate scant information in this area as well as some urgent work to ensure students' good health in the time of the COVID-19 pandemic are suggested as the future direction.

Future Direction

The future directions are:

1. For the design, construction, and operation of new as well as existing buildings to prevent them from the indoor transmission of SARS-CoV-2-like viruses, a special publication as an annexure to the National Building Code or a separate document is required. The authors are working on these guidelines.
2. All naturally ventilated schools, as well as naturally ventilated buildings, need an economical retrofitting solution or device to tackle IAQ problems (virus transmission) inside classrooms. The authors are researching this.
3. Air-conditioned schools, as well as spaces in schools such as libraries, computer labs, auditoriums, digital classrooms, and other air-conditioned buildings, need an urgent solution to decontaminate the air. Therefore, the authors are researching this direction

to prevent the SARS-CoV-2 or other similar airborne pathogens transmission through devices installed in air-conditioned buildings.

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