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Review Paper

A review on indoor air pollution and associated health impacts with special reference to building designs

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Abstract

Human spends most of the time (about 90%) of their lives within indoor environment.The way we design buildings and operate in the indoor setting has a profound impact on human health. For understanding of how building design in urban environment, effects human health there is a necessity of study "buildings as an ecosystem". The international status of the information on the theme of "indoor air pollution", "building design" and its "impact on human health" and the search engines like Scopus, PubMed, Web of Science and JSTOR were used and retrieved information in the form of published papers in peer-reviewed journals who at least include two criteria pollutants (CO, CO_2, Bioaerosols, VOCs, PM_{10} and $PM_{2.5}$) in residential areas.Over last 30 years (1988-2017) about 908 documents were identified on global scale. Out of which 14 studies were satisfied the inclusion criteria rest were excluded due to duplicated reports, not related to the field, reviewed papers, some were not provided relevant data. Published papers in peer-reviewed scientific journals are providing inadequate information on building design, indoor pollution and possible health effects. Tagging above knowledge gap, there is a clear need for further studies to relate indoor air pollutants (either in residential or in commercial building) and its impact on health, especially in diverse climatic locations with polluted outdoor air.

Keywords: Indoor air pollution, building design, built-up environment, sick building syndrome and health effect.

Introduction

Human devote almost 90% of their day today life either inside their workplace or inside homes[1]. Indoor air quality (IAQ) of building is a basic indicator of health quality, comfort and productivity of occupants. The interaction between the construction site, building design, construction techniques, contaminants sources and respondents activities are the major factors which influence indoor air quality. Consequently, the way we design buildings and pollute our indoor environment has impact on our health[2]. For the better understanding of the issues (linking building design, indoor pollution and human health) there is an urgent need to study "*buildings as an ecosystem*". Built environments are complex ecosystems where diverse pollutants regularly emitted which are either chemical or biological in nature, examples trillions of microorganisms, volatile organic compounds (VOCs) and other gaseous and particulate pollutants[3].

Building materials and furnishings items regularly emit toxic air pollutants like different types of VOCs which have severe impact on human health. Human lifestyle and daily activities (like cooking, washing and cleaning) mainly enhance the pollutant level within a building. Till now the influencing factors which determine the diversity and composition of the indoor air pollutants and human health are poorly understood. To fling the knowledge gap, we have proposed the study and reviewed in detail the available national and international literature database.

Methodology

Worldwide indoor air pollution, building design and associated health risk has been studied extensively[4-7]. To find out the national & international status of the information on the theme of indoor air pollution, building design and its impact on human health, different combination of keys words were used by the search engines like Scopus, PubMed, web of science and JSTOR and retrieved information in the form of published papers in peer reviewed journals where atleast two criteria pollutants (CO, CO_2, Bioaerosols, VOCs and PM_{10}, $PM_{2.5}$) were included and did sampling exclusively in urban residential area.We manually searched the references of every published study for additional publications and all the other review publications were also identified by examining for the study. Over last 30 years (1988-2017), about 908 documents were identified on global scale. Out of which 14 studies were satisfied the inclusion criteria, rest were excluded for various reasons like duplicated, only reports, not related to the field, reviewed papers or some papers were not provided relevant data (Figure-1). Publications only in English language were included in this study.

Documents were available majorly in the subject areas of Medicine, Environmental science, Engineering and Social science.Maximum work had been reported in Medicine and in environmental science particularly from United States (US) followed by European Union (EU), United Kingdom (UK) and Australia.

Gustafson et al[8] published a study on building design and its impact on human health and encourages people to think a new research first time. In last three decades, globally lots of work had been done on sick building syndrome (SBS) and its impact on human health. Many more national studies are needed to be done (with a extensive research base) on the theme of "SBS and Human Health". Major associated risk factors are linked with this theme discussed below:

Indoor pollutants: Indoor pollutants are mainly classified into three categories (physical, chemical and biological) based on the source and nature (Table-1).

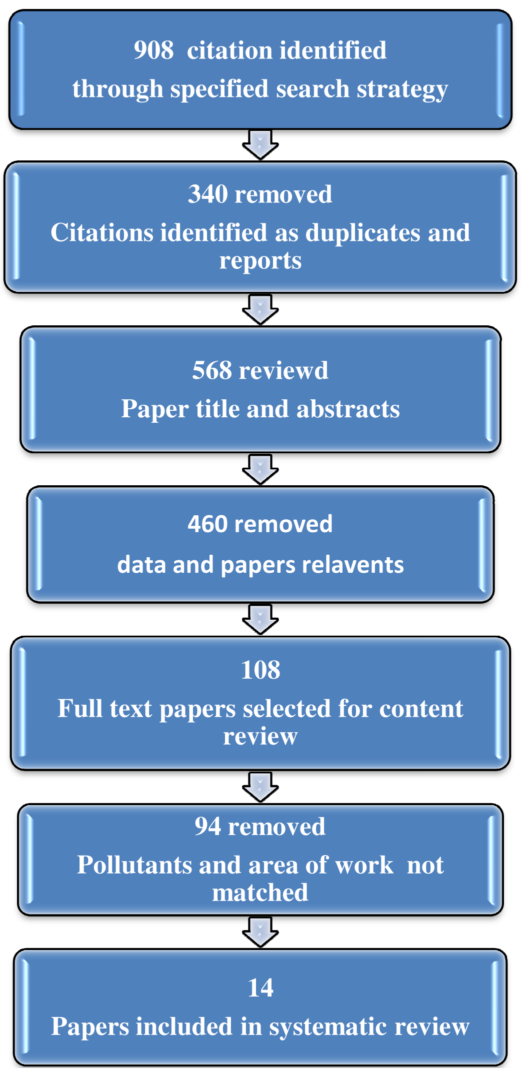

Figure-1: Flowchart of search strategy and selection criteria.

Table-1: Classification of causative agents responsible for Indoor air pollution

Type of causative agent	
Biological pollutants	Bioaerosols (fungi, molds, bacteria, danderonetc.)
Chemical pollutants: a. Gaseous pollutants	Toxic gaseous pollutants, VOCs, Environmental Tobacco smoke (ETS)
b.Trace Metal Particulate pollutants	Trace metal enrich PM_{10}, $PM_{2.5}$, PM_1
Meteorological factors	Humidity, Wind circulation and Thermal environment

There is well established link between the health of inhabitant and indoor air pollutants, IAQ define as quality of air within and around the buildings, represented by the concentrations of pollutants and thermal (irrespective to relative humidity and ambient temperature) environment. In urban environment, indoor air quality problems have been fostered due to rampant usage of chemicals by the individual, tighter close building envelopes with less ventilation and other poor facilities (like faulty building design).

Particulate Matters(PM) is sum of solid and liquid particles (organic and inorganic in nature) in air which affects more people than any other gaseous pollutants. Majorly PM, includes both organic and inorganic particles, comprises of sulfate, nitrates, sodium chloride, ammonia, mineral dust, black carbon, bioaerosols and water droplets. The particulate matter most dangerous to human being those with a diameter of 10 microns or less, (≤ PM10), which can penetrate and lodge themselves deep inside the lungs[9] or in other parts of the body. Long-lasting exposure to these particles contributes to chances of developing cardiovascular and respiratory related diseases; additionally it can be responsible for lung canceralso[10].

Tobacco smoke is also a major public health concern due to high smoking habits of younger as well as older generation in India which is a very normal practice within villages and cities as well. According to WHO (World Health Organization) report[11], there are 14 % of adult in India habitually tobacco smoker these number become more massive in terms of India's robust population density. Tobacco Smoke which comprises more than 4000 chemicals[12], most of them are harmful and toxic in nature. The smoking habits affect not only active smoker but passive smoker too. Desouky et al[13] conducted a study in Saudi Arabia, to find out the link between exposure in Environmental Tobacco Smoke (ETS) and quality of urine among students. They had reported that mean urinary cotinine (Cotinine is similar to nicotine, used as a biomarker for exposure to environmental tobacco smoke) was reported significantly higher concentration among teenagers who exposed to ETS compared to unexposed ones. In another study among children reported significantly higher urinary cotinine levels with multiple exposures were compared to its level with single exposure to the children.A strong positive correlation was established between urinary cotinine concentrations and the number of cigarette packs per day smoked by parents and the number of smokers inside house. The average cotinine level in urinary was significantly higher in children whose family members were habituated smoker at home.

Bioaerosol as a potent pollutant: Aerosol particles having biological in origin are termed as 'bioaerosols', which include bacteria, fungi, viruses, pollen and spores as well as their byproducts. The presence of pathogenic bio-aerosols in indoor spaces is often linked with Sick Building Syndrome (SBS) and Building Related Illness (BRI)[14]. There are number of sources of bioaerosols inside building like building construction materials, furnishing items and; fungal growth within ceiling, in thick wall and also in floor cavities and spores via wall openings and gaps at structural joints[15]. The common airborne fungi causing respiratory infections and allergic reactions are dominated by genus *Penicillium, Acremonium, Aspergillus, Paecilomyces, Mucor* and *Caldosporium*[16]. Bacteria and fungi (Bioaerosol) are abundant in the atmosphere, indoor development can cause many fungal and bacterial diseases such as infections, allergies or toxic reactions[17]. About 42% of the population in developed world has allergies against biotic and abiotic environmental agents, and three hundred million people globally suffered from 'asthma'. Exposure to biological allergens which ultimately triggers bronchial Asthma (via touching surfaces person-to-person contact or inhalation) is often arbitrated with inambient enclosed environment[18]. Bioaerosols exposure could be responsible for respiratory infection and other health related problems such as skin infections, hypersensitivity pneumonitis and other harmful reactions[16]. Fungi are ubiquitous in ambient (indoor and outdoor) environments and worldwide nearly one tenth of populations are reported to have fungal allergy[19].

Indoor air quality get worsen due to moisture, dampness and mold problems within buildings and it is also well linked with health effects such as respiratory symptoms and asthma. In modern building, frequently various signs of dampness or moisture based damages are visible[6] and the occurrence of mold varies between 1.5-20%[19]. Although fungal spores are ubiquitous in nature but it grow and develop into visible mold only when suitable moisture and dampness are unrestrained. General practice use for, like application of fungicides or disinfectant products do not solve the problem and may even be an additional burden to indoor chemical exposure. Humidity regulation generally difficult within an existing building, and therefore after the development of damaging mold needs time to dry. In the future, urban communities are normal that the development materials of a building ought to be strong and impervious to microbial development. All type of microbial exposure should be viewed on the basis of the nature of pathogenic microbiome, whether it belongs to a transient or in a steady community. Designing our in built environment in such a way to promote beneficial microbial exposures is not yet feasible. Designing our inbuilt up environment in such the simplest way to push useful microbial exposures isn't however possible because the identification and concentrations of useful microbes still underway, researcher should concentrate on improving ability to foresee how constructing attributes sway building microorganisms and shapes the human microbiome.

Air conditioning system: In air-conditioned buildings, indoor air quality is dependent on the effectiveness of cooling and humidifier frameworks since these e-structures give an appropriate domain to the expansion of microbes[20]. Dispersion of indoor air pollutants like bioaerosols in environment through the air-conditioning system playsa pivotal role.

'Humidifier fever**'** could be a disease with similar symptoms of **'**hypersensitivity pneumonitis**'** associated with bacteria, fungi and endotoxins that found among humidifier reservoirs, air conditioners and additionally in aquaria**.** The common associated sickness is characterized by uneasiness, headache, fever, chills and myalgia**.** It unremarkably subsides among twenty four hours while not residual effects**.** Humidifier respiratory organ sickness with cough fever, pain and hurting was delineated as a result of inhaling endotoxin present in the humidifier water[20].

Volatile Organic Compounds (VOCs): organic compound defined as chemical compound that contains no less than one carbon and a hydrogen atom in its sub-atomic structure. VOCs are those having initial boiling point less than or equal to 250°C (ranges between 40°C to 250°C) because of that they will readily emit gas vapors into indoor air. However, use of VOCs in construction projects is widespread and materials containing VOCs should exhibit desirable characteristics of good insulation properties, resistance, and ease of installation[21]. Different types of available common VOCs, and their source which are generally found within Indoor environment are represented in Table-2.

The VOCs exposure can result in both intense and chronic health impacts. Asthmatics and different people with earlier respiratory issues might be especially prone to low-portion of VOCs doses[22]. The common sources, characteristics of indoor air pollutant and their human health effects[23] discussed in detail (Table-3).

Indoor pollution and meteorological parameter: Meteorological parameters plays a crucial role in the dispersion of pollutant not only in outdoor environment but also within indoor environment as well. Various indoor pollutants like VOCs, bioaerosols, particulate matter and other gaseous pollutants like carbon monoxide (CO) and carbon dioxide (CO_2) react differently within indoor environment. Diverse meteorological parameters as for e.g. temperature, humidity, wind speed and solar radiation affect the pollution level in closed environment. In Indoor environment, it is necessary to regulate moisture, temperature and rate of air circulation speed within recommended limit. Presence of high dampness and dirt can be a reason for molds and other biological contaminants to flourish[6]. If moisture levels are remain normally high within indoor environment it may be lead to the bioaerosols growth and dispersion and if humidity levels remain too low may reason of irritation in eyes, mucous membranes and lead to sinus discomfort. Indoor temperature and pressure differ in comparison to outdoor environment play a major role in pollutant dispersionprocess[2]. Air moves from a region of high pressure to low pressure so regulating building pneumatic force is a vital piece of controlling contamination and which at last upgrade building IAQ (indoor air quality) performance.

Table-2: Typical volatile organic compounds within indoor environment[21].

Sources	Examples of typical contaminants
Building materials	Aliphatic hydrocarbons (*n*-decane, *n*-dodecane), aromatic hydrocarbons (toluene, styrene, ethylbenzene), halogenated hydrocarbons (vinyl-chloride), aldehydes (formaldehyde), ketones (acetone, butanone), ethers and esters (urethane, ethylacetate).
Paints and associated supplies	halogenated hydrocarbons (methylene chloride, propylene dichloride), alcohols, ketones (methyl ethyl ketone), esters (ethyl acetate) and ethers (methyl ether, ethyle ether, butyl ether)
Furnishings and clothing item	Aromatic hydrocarbons (styrene, brominated aromatics), halogenated hydrocarbons (vinyl chloride), aldehydes (formaldehyde) and esters.
Adhesives	Aliphatic hydrocarbons (hexane, heptane), aromatic hydrocarbons, halogenated hydrocarbons, alcohols, amines, ketones (acetone, methyl ethyl ketone), esters (vinyl acetate) and ethers.
Consumer and commercial products	Aliphatic hydrocarbons (*n*-decane, branched alkanes), aromatic hydro carbons (toluene, xylenes), halogenated hydrocarbons (methylene chloride), alcohols, ketones (acetone, methyl ethyl ketone), aldehydes (formaldehyde), esters (alkyl ethoxylate), ethers (glycol ethers) and terpenes(limonene, alpha-pinene).

Table-3: Indoor air pollutants with their sources and health effects.

Pollutant	Sources and characteristics	Associated health effects
Particulate matters	PM10/PM2.5/PM1 Motor vehicles, wood burning stoves and fireplaces. Dust from construction, landfills, agriculture & Industrial site	Irritation of the air-ways, coughing, or difficulty in breathing, decreasing pattern in lung function, chronic bronchitis; asthma, heart or lung disease
	Asbestos**:** insulation of heating gadget and mixed with cement, it is used for roofs and water deposits.	Known human carcinogen and synergic effects with tobacco smoking impact increase approximately five fold.
Radon	A naturally occurring gas (air, water and soil)produce by geological activities.	Carcinogenic in nature especially to lung cancer. Radon can cause synergistic bad effect on health related issues.
Gaseous pollutants	Carbon Dioxide (CO_2) produced by cellular metabolism, combustion activities	At higher concentrations increased respiratory rate, tachycardia, convulsions, coma and death.
	Carbon monoxide (CO): from incomplete combustion	Binds with hemoglobin, reduce transport of oxygen. Headache, nausea & dizziness
	Nitrogen oxides (NO_x)**:** fossil fuel burning,	Irritant, affecting the mucosa of eyes, nose, throat and respiratory tract
	Sulfur dioxide (SO_2), Main source coal & wooden based cooking	Irritates and inflammation in mucosa lining of eyes, nose, throat, lungs. High concentration leads to asthma attacks and worsen cardiac and respiratory systems.
	VOCs (daily routine products, building materials, cosmetics and domestic products and fuel burning)	Irritation in eyes, nose and whole respiratory systems , long and high concentration can damage liver, kidney and CNS.Adverse effects on eyes and also in upper and lower respiratory tract, Carcinogenic in nature
	Tobacco smoke (TS): Complex mixture of more than 4000 identified chemicals,causing toxic or carcinogenic in nature.	Children: acute lower and upper respiratory infections, bronchitis, bronchiolitis and pneumonia, tuberculosis, severe asthma Adults**:**difficulty in breathing, exacerbation of respiratory disease like COPD and cardiovascular disease (heart stroke and Heart attack)
Biological Pollutants	Bacteria, molds, dust mites, fungus, products from men and pets, pests (mice, cockroaches, rats). Microbial products (endotoxins, microbial fragments etc.	Allergic reactions (rhinitis conjunctivitis etc.),Asthma, COPD, hypersensitivity pneumonitis, Legionellosis, Sick building syndrome and toxic reactions

Building Design: Building design plays a significant role in accumulating indoor pollutant concentration. It has many aspects like ventilation pattern, inner wall composition, direction of house, Kitchen (as a source) position inside house, window and door position, roof height from ground, construction material used in building, paint and coating of wall beside flooring (carpet and non-carpet area) etc[24]. If the building design are faulty then indoor air pollutants start accumulating with in close confined space[25]. People and their day-to-day activities, building construction materials, different steps of renovations like furnishings, paints, wooden work and closed combustion and other emit pollutants within the indoor air[26] whereas ventilation or air exchange capacity of the building is intended to remove emitted pollutants and ultimately reduce their concentrations in occupied spaces. Spatio-temporal pollutant variation which was observed inside and outside of a building possibly affect public health whether breathe in outdoors or indoors environment. The ventilation system can also serve as a way of bringing outdoor contaminants into indoor spaces of building. Physiochemical reactions which happen in indoor environments alter the composition of indoor ambient air it lead to effects indoor ambient air and health of exposed occupants. Generally, the reliance of indoor pollutant concentration on air exchange rate differs among pollutants but it has not been completely characterized till now.

All around, the aim of air exchange in any confined area is to supply fresh air in indoor spaces to the inhabitants and to take out generated heat from the enclosed spaces. A research study had been explained the building structure design features of an indoor environment, which comprises air exchange and design of improvements, can improve the health status of the residents and deliver a improved working atmosphere for the office employees[27]. Engvall et al[6] had reported strong correlation between ventilation (air exchange/circulation) and the spread (transmission) of contagious diseases such as smallpox, chickenpox, measles, influenza, tuberculosis and Severe Acute Respiratory Syndrome (SARS) within indoor environment. Wong and Huang[4] showed in their study most of the residents that practically all inhabitants who utilized air-conditioners systems amid sleeping showed at least one SBS indications even shown more SBS side effects in the wake of utilizing cooling contrasted with utilization of natural ventilation.

Qian et al[28] conducted a study on naturally air exchange in hospital wards of Hong Kong city and reported advantage of natural ventilation for infection control in hospital wards and reported that natural aeration were more effective (high air circulation rates), especially when the windows and the doors were placed in opposite wall in a ward. The high air exchange rate[29] provided by natural aeration can decrease cross-infection of airborne diseases, and thus it is suggested for using of practice in appropriate hospital wards for disease control. Chan et al[2] had encouraged to improve building air exchange by using regular opening of windows and also recommended to use an exhaust fan in toilet and bathroom to decrease domestic mold/dampness and also to control air pollution emissions during home renewals.

Ventilation rates within building: Emissions of toxicant vary greatly either temporarily or spatially within the buildings. Ventilation (air exchange) can work as a way of introducing these pollutants within enclosed areas. Physiochemical reactions which happen within enclosed environment alter the composition of indoor air and apparently affect both the air quality and become health associated risk for inhabitants.

Sick building syndrome (SBS): a complaint in which occupants of building (residential/official) people in a building feeling unwell and facing symptoms of illness for no apparent reasons. The complaints may probably intensify in severity as a proportional of time spent within building or recover over time and even disappear when individuals left the specific building[5]. Some specific and non-specific symptoms are listed in Table-4.

Table-4: List of common observed SBS (sick building syndrome) symptoms.

Eye symptoms	Dryness, redness and irritation, Itchiness and watering and pain in the eyes
Nausea, dizziness	Sensation of dry mucous membranes and skin
Respiratory tract symptoms	Cough, congestion, nosebleeds, dryness and irritation in the nose and throat, irritation of the nasal mucous membranes, pharyngeal symptoms, sinus pain and exacerbation of asthma and High frequency of airway infection and cough
Skin symptoms	Erythema (Superficial reddening of the skin)
General symptoms	Mental fatigue, Headache, Hoarseness, wheezing, itching and unspecific hypersensitivity

Establishing sick building syndrome is always a challenging task especially when people's symptoms are relatively mild and possibility of having other causative agents. General sick building syndrome is neither disabling nor dangerous[30], but the cases of sick building syndrome among working class or in residential population does have an economic impact[31], SBS can negatively affect the work efficiency of people, if someone experience SBS symptoms at home, that illness may also be carry pass on to the place of work, so impacting the effects of SBS on persons efficiency at their workplace too. Since last several decades SBS has been acknowledged as a major concern in the America,, Canada, Australia, Japan and European countries in but subtropical counties like India whose environment generally remain humid and hot throughout the year never addressed this issue although geographical location is more prone towards having SBS illnesses.

In general among all "sick leaves" respiratory illness accounts for a large fraction[32-34]. Sick leave (data of employee) is outcome that could be used to study the health status within indoor environment. This database has been used very frequently for epidemiological study like indicators for respiratory diseases among agricultural workers, or to identify ergonomic problems[35]. Teculescu et al[36] described that the inhabitants of naturally ventilated building complaint lesser SBS symptoms and took less leave from work compare to the persons who residing in an air-conditioned building a in North-eastern France. However, the study work was undertaken only in two buildings and due to absence of control of air exchange rates and sample size was not large that may have proved the strong relationship between sick leave and particular building.

Human health: Various household products generally we use alone or used simultaneously with other cleaning or cosmetics products. Similar observation[22,37] had been found that there can be `dependence of an individual on the regularity, extent, types and exposure of product such as cleaning and Cosmetics product, hair-styling products dishwashing detergents, pesticides[38]. Generally day-today activities can increase exposures to VOCs up to a factor of hundred compared to the exposure during resting time and also far above the observed outdoor concentrations. Consumer products with particular indoor chemical exposures are many which include deodorizers, the dishwasher and laundry detergents, tobacco product, paints and the paint remover[39].

In addition, consumer product combinations or a mixture of consumer products with outdoor air can also act as irritants in the respiratory tract. Air fresheners and cleaning agents may contain certain chemicals that react to other air contaminants to produce potentially harmful secondary products, such as terpenes that can react with indoor air ozone to produce other secondary pollutants[40,41].

Review of studies mitigating SBS and indoor air quality

On global scale very few studies were conducted which correlate indoor air quality, sick building syndrome and building design. During 1990, Norback et al[7] in Sweden, surveyed continuously for three years in 10 buildings and multi factorial in consecutive cases of sick buildings, study was conducted to investigate the relationship between SBS symptoms, environmental exposure and individual aspects. Total concentration of indoor hydrocarbons was significantly associated with SBS symptoms. There was no correlation with SBS between other indoor factors such as room temperature, relative humidity, concentration of formaldehyde (HCHO) or carbon dioxide (CO_2). But the sick building syndrome was strongly associated with individual personal factors such as reported hyper reactivity or sick leave due to respiratory dysfunction.

Norbick et al[22], in Sweden, conducted cross sectional study between Asthmatic symptoms and VOCs concentration in dwelling and suggested that VOCs and formaldehyde in indoor environment possibly can cause asthmatic issues. Their study comprises 88 subjects and measured room temperature, ambient humidity, respirable dust, carbon dioxide (CO_2), VOCs and formaldehyde in different houses. Overall study suggested that necessity to enhance the outdoor air supply in many buildings, and wall to wall carpeting and dampness in the building should be avoided. Indoor air quality can be improved by choosing materials of building construction, building construction processes and daily activities in indoor area. Sources of emission VOCs should be as low as reasonably possible to further minimize asthma-related symptoms. Engvall et al[6] tried to determine the association of SBS in relation to building dampness in multi-family building in Stockholm. In this study, 4,235 dwellings were identified and bioaerosols, VOCs and PM concentrations were established. In multi-family buildings in Stockholm, high humidity as well as structural building dampness were common. Building dampness is directly associated with a pronouced increase in SBS symptoms, regardless of age, gender, population density, and risk factors associated with building.

Wong and Huang[4], attempted to find association of the quality of indoor air in bedrooms of residential buildings by using naturally ventilated and air-conditioned in Singapore area. The study showed a comparison between air-conditioned and non-air-conditioned bedrooms, with almost all occupants using air-conditioners during sleeping showing one or more SBS symptoms, and these occupants usually showed more SBS symptoms after using air-conditioning than when using natural ventilation. The study also revealed that air conditioning's frequency and duration of use has a significant impact on the exhibition of SBS symptoms. A study by Cataneo et al[42] in Italy reported that Indoor environment had more key pollutants like NO_2 and $PM_{0.5}$, that may pose health concern to the residents. At Delhi residential homes, Kulshreshtha and Khare[43] evaluated indoor exploratory analysis of gaseous pollutants and respiratory particulate matter. In a study, concentrations of pollutants such as CO, NOx and particulates (PM10, PM2.5 and PM1) were measured in 8 homes during winter and summer seasons. Study concluded that there are major sources of RSPM and CO indoors, primarily for cooking using biomass as fuels as well as manually cleaning homes. Study also suggested that the indoor RSPM concentrations were mainly composed of finer range of particles.

In next year Kulshreshtha and Khare[9], again published a new study about Indoor gaseous pollutants and respirable particulate matter at residential homes of Delhi, India. In the study PM_{10} and $PM_{2.5}$, Carbon Monoxide, Sulphur dioxide and the nitrogen dioxide pollutants monitored and at the same time 60 person surveyed and had undergone spirometry for assessing respiratory health. Study concluded that women and children are most vulnerable compared to men to respiratory problems because they spend maximum time in indoors. High SBS scores were observed in these households along with higher prevalence of respiratory symptoms due to inefficient ventilation, poorly designed houses and the use of biomass fuels for cooking. To check diurnal and seasonal variation in different indoor environment multiple comparisons of organic, microbial, and fine particulate pollutants were done by Mentese et al[37], in Turkey. The seasonal and diurnal variations of VOCs, PM2.5 and bioaerosols in houses, offices and in schools were observed, in which except VOCs, PM2.5 and bioaeorosols showed marked daily variability. Norhidayaha et al[44], tried to find out association in indoor air quality and sick building syndrome in three selected building in Malaysia where fungi count, CO_2, CO, temperature and relative humidity were monitored along with survey of 63 people. The field investigations in buildings had shown that the admissible limits of pollutants were often exceeded for a prolonged time; especially in a ratio of 1:3 and at the same time SBS symptom were more prominent in that building. In a Guo et al[5] study on indoor air quality and sick building syndrome, very low concentrations of VOCs and formaldehyde were noted in the residential area, so that prior high-level exposure to these chemicals should be considered among residents who once experienced SBS-related symptoms. Current low-level exposure to butanol,1,1,1-trichloroethane, p-xylene, methyl isobutyl ketone, or styrene could cause these symptoms. They suggested that these chemicals ' exposure limits should be evaluated and established in order to prevent SBS through further study.

In 2014, Colton et al[27], attempted to find out association of indoor air quality in green vs conventional multifamily low-income housing in Boston, USA. Participants in green homes experienced 47% fewer sick building syndrome symptoms ($p < 0.010$) compare to conventional building. Study tried to establish that green buildings are more superior then conventional building. Lu et al[2] in China, conducted a cross sectional study between indoor/outdoor air pollution with meteorological conditions factors in relation to SBS in population adults. Study concluded that females were more susceptible than men in SBS symptoms.

Table-5: Listed referred papers which discussed in my study.

Reference no. & Study site, Country	Pollutants Consider	No. of participants & study type	Finding
5 Dalian, china	Temperature, air humidity, Formaldehyde (HCHO), NO_2, VOCs	109 residents (59 males and 50 females) Cross-sectional	HCHO, butanol, or 1,2-dichloroethane high concentration can initiate SBS in indoor environment. Low-level exposure of chemical like butanol, 1,1,1-trichloroethane, p-xylene, methyl isobutyl ketone or styrene and VOCs could be caused SBS symptoms. Study stress upon more research on exposure limits of these chemicals evaluation and established by further study to prevent SBS.
6 Stockholm, Sweden	Temperature, air humidity, Bioaerosols, VOCs, $PM_{2.5}$ and PM_{10}	4,235 residents Cohort study	Signs of high humidity and building structural dampness were common in multi-family buildings. Dampness in dwellings was associatedwith increase of SBS symptoms in residents. Age, gender, population density and building-related risk factors also influence the dwellers' health.
7 Uppsala, Sweden	Temperature, air humidity, CO, CO_2 and VOCs	110 residents for three-year period. Cross sectional	Hydrocarbon concentrations in indoor were significantly related to SBS symptoms but other physical exposures i.e. temperature, humidity and pollutants like formaldehyde or CO_2 concentration not associated. Personal factors like hyper reactivity and sick leaves due to airway diseases were strongly related to the SBS.
9 Delhi, India	Temperature, air humidity, PM_{10} and $PM_{2.5}$, CO, SO_2, NO_2	60 residents Cross sectional	In indoor environment, women and children are more expose to respiratory illness compared to men. Prevalence of respiratory symptoms and SBS complaints had been more observed in these households because of using of biomass fuels for cooking, poorly designed houses and inefficient ventilation inside houses
10 Bangladesh Dhaka	Temperature, air humidity, CO, CO_2 , NO_2 hydrocarbon, formaldehyde	97 houses and 288 individual Cross sectional	In indoor environment concentrations of some air pollutants (i.e. carbon dioxide, formaldehyde and hydrocarbon) were higher and the members of these households were observed more prone to respiratory diseases and other SBS symptoms.
22 Uppsala, Sweden	Temperature, air humidity, PM_{10}, $PM_{2.5}$, CO_2, VOCs, HCHO and dust mites	88 residents Cross sectional	Indoor VOCs and HCHO may cause asthmatic symptoms. Study emphasizes on need to increase ventilation of outdoor air in some houses. Wall to wall contact and dampness of the building should be avoided. IAQ depend on selecting type of building materials, building design and indoor activities.

27 Boston USA	Temperature, air humidity, $PM_{2.5}$, formaldehyde, NO_2, CO_2, and air exchange rate (AER)	61 residents (43 in conventional building and 18 in green building) Cross sectional	Participants in green homes experienced 47% fewer SBS symptoms compare to conventional houses**.** Study indicates significant decreases in multiple indoor exposures and SBS symptoms among participants who moved from conventional to green housing.
31 China	Temperature, air humidity, PM_{10}, SO_2, NO_2	Questionnaire 3485 and three months monitoring Cohort study	Females were more susceptible towards SBS compared to men**.** Study fails to link SBS with outdoor air pollutants or with meteorological parameters**.** SBS symptoms (specially fatigue, eyes and nose symptoms) were strongly associated to indoor**-**outdoor factors like SO_2, temperature and RH**.** Indoor mold, pollutants from renovation and low ventilation in buildings can cause to SBS symptoms in Chinese population (especially females).
38 Ankara, Turkey	Temperature, air humidity, Bioaerosol VOC, $PM_{2.5}$	5 buildings and 213 residents Cross sectional	$PM_{2.5}$ and bioaeorosols showed marked both intraday and seasonal variability, but VOCs did not**.** VOC**-**containing products were the most common source of indoor air pollutants. Quality of IAQ govern by external factors mainly ventilation rate and outdoor air pollutants concentrations.
44 Lodi, Italy	Temperature, humidity, PM_{10} and $PM_{2.5}$, CO, SO_2, NO_2	60 homes Cross sectional	$PM_{2.5}$ and NO_2concentration frequently higher and all other studied pollutants concentration lower than national guidelines**.** A strong seasonal trend observed among pollutants, highest level in winter season (especially $PM_{0.5}$) and lowest in summer.
45 Delhi, India	Temperature, air humidity, CO, NO and PM_{10}, $PM_{2.5}$ and PM_1	8 homes Two season (winter and summer) Cross sectional	RSPM and CO exist within indoors that is primarily contributed by cooking using the fuels (biomass based) and cleaning of homes manually, particularly at commercial site. Study also suggests that the finer range of particles concentration were maximum in RSPM in indoor spaces.
46 Malaysia	Temperature, air humidity, wind velocity, Fungi count, CO_2, CO, concentration	3 building and 63 residents Cross sectional	Admissible limits of pollutants were often exceeded for a prolonged time; especially one building out of three. In Indoor areas the SBS symptoms observed in residents where ventilation rate low and buildup of possible contaminants sources in building.
47 Canakkale, Turkey	Temperature, air humidity, VOCs and CO_2	6 Houses Cross sectional	Indoor CO_2 levels were found to be higher than outdoors**.** The highest indoor CO_2 levels were found in industrial sampling points, whereas the lowest CO_2 levels were found in urban sampling points**.** No clear seasonal variations in VOC levels were observed at the sampling sites.
48 Setúbal, Portugal	Temperature, air humidity, $PM_{2.5}$, PM_{10}, VOCs, CO, CH_2O & CO_2	3 building, 105 residents Cross sectional	Some indoor pollutants i.e. VOCs, formaldehyde, CO_2 and PM2.5 reached concentrations above the established guidelines and infiltration of specific pollutants in bedroom, from outdoors or from other spaces of the house (e.g**.** kitchen) also affect IAQ**.**

No associations with SBS were observed in the final models for outdoor air pollutants or meteorological parameters combining indoor and outdoor factors, although some SBS symptoms (fatigue, eyes, and nose symptoms) were associated with temperature and relative humidity in the separate outdoor models SO_2. Indoor bioaerosols can be risk factors for SBS symptoms in an adult Chinese population, particularly among women, due to humidity, redecoration air pollution and insufficient ventilation conditions in dwellings. Nahar et al[10], conducted a cross**-**sectional study between indoor air pollutants and respiratory problems in Dhaka, Bangladesh**.** Study revealed that most of the indoor air pollutant concentrations were higher than outdoor ones**.** The residents suffered more from respiratory disease, especially those households with significantly higher air pollutant concentrations (formaldehyde, carbon dioxide and other hydrocarbons). Mentese and Tasdibi[45], reported assessment of residential exposure of VOCs and Carbon Dioxide (CO_2) in Turkey and the study didn`t reveal that the concentrations of both of them were always higher.

Study published in 2017 by Canha[46] et al, observed that during sleeping time indoor pollutants were higher because doors and windows usually closed and indoor pollutant concentration were higher most of the time compare to outdoor.

Among all the studies, only two papers (Kulshrestha et al[9,43]) are from India, rest of the studies were done mainly in European countries and they were associative in nature. There is a paucity of cohort studies which can only help to understand the exact role IAQ and SBS in reference to building design.

Study limitation: Despite few interdisciplinary researches on indoor air qualityin relation to sick building syndrome (SBS) mainly in Residential /offices complexes, still we have an incomplete understanding of this complex issue in India. There is a dire need to study more on building design and rational modification of building design.

Conclusion

The residents who expose themselves in unhealthy indoor environment reported more SBS related complaint. This study attempted to advocate the important role of building design and their significant impacts on occupant's health through exploring the negative effects of buildings related illness (BRI). This review critically analyzed that sick buildings are passively affecting resident's health status but actively affecting their work potential.

On the other hand, the concept of healthy building has been talked through emphasizing its main encouraging points like maintainable indoor air quality and also identified many parameters which are major contributors for SBS like psychological, biological, physical or chemical.Reviewing recent studies[47,48], it has been categorically revealed that design of buildings and its physical characteristics can influence directly appearance of SBS symptoms. The health impact can be carefully minimizes specifically during the operational (construction) phase of building by certain architectural changes (building orientation or using quality building material).

Modifications in building design may potentially facilitate air exchange rate throughout the building and will also manage to receive sufficient amount of solar radiations to provide a required amount of illuminance for occupants. Indoor air pollution is a dynamic process with complete varied responses in different climatic zone either in tropical or in temperate climate. To safeguard our community health a national standard or guideline is urgently needed in India.

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References

1. Klepeis N.E., Nelson W.C., Ott W.R., Robinson J.P., Tsang A.M., Switzer P. and Engelmann W.H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science and Environmental Epidemiology*, 11(3), 231.
2. Lu C., Deng Q., Li Y., Sundell J. and Norbäck D. (2016). Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China. *Science of the Total Environment*, 560, 186-196.
3. Amend A.S., Seifert K.A., Samson R. and Bruns T.D. (2010). Indoor fungal composition is geographically patterned and more diverse in temperate zones than in the tropics. *Proceedings of the National Academy of Sciences*, 107(31), 13748-13753.
4. Wong N.H. and Huang B. (2004). Comparative study of the indoor air quality of naturally ventilated and air-conditioned bedrooms of residential buildings in Singapore. *Building and Environment*, 39(9), 1115-1123.
5. Guo P., Yokoyama K., Piao F., Sakai K., Khalequzzaman, M., Kamijima M. and Kitamura F. (2013). Sick building syndrome by indoor air pollution in Dalian, China. *International journal of environmental research and public health*, 10(4), 1489-1504.
6. Engvall K., Norrby C. and Norbäck D. (2001). Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm. *International archives of occupational and environmental health*, 74(4), 270-278.
7. Norbäck D., Michel I. and Widström J. (1990). Indoor air quality and personal factors related to the sick building syndrome. *Scandinavian journal of work, environment & health*, 16, 121-128.
8. Gustafson T.L., Lavely G.B., Brawner E.R., Hutcheson R. H., Wright P.F. and Schaffner W. (1982). An outbreak of airborne nosocomial varicella. *Pediatrics*, 70(4), 550-556.
9. Kulshreshtha P. and Khare M. (2010). A comparative study of indoor air pollution and its respiratory impacts in Delhi, India. *WIT Trans. Ecol. Environ*, 136, 287-296.
10. Nahar M., Khan M.H. and Ahmad S.A. (2016). Indoor Air Pollutants and Respiratory Problems among Dhaka City Dwellers. *Arch Community Med Public Health,* 2(1), 032-036. DOI: 10.17352/2455-5479.000014. *Archives of Community Medicine and Public Health*, *32*.
11. World Health Organization and Research for International Tobacco Control (2008). WHO report on the global tobacco epidemic, 2008: the MPOWER package. World Health Organization.
12. El-Shazly A.A.E.F., Farweez Y.A.T., Elzankalony Y.A., Elewa L.S. and Farweez B.A.T. (2018). Effect Of Smoking On Macular Function And Structure In Active Smokers Versus Passive Smokers. *Retina*, *38*(5), 1031-1040.
13. Desouky D.S., Elnemr G., Alnawawy A. and Taha A.A. (2016). The relation between exposure to environmental tobacco smoke and the quantity of cotinine in the urine of

school children in Taif City, Saudi Arabia. *Asian Pac J Cancer Prev*, 17, 139-145.

14. Yassin M.F. and Almouqatea S. (2010). Assessment of airborne bacteria and fungi in an indoor and outdoor environment. *International Journal of Environmental Science & Technology*, 7(3), 535-544.

15. Srikanth P., Sudharsanam S. and Steinberg R. (2008). Bio-aerosols in indoor environment: composition, health effects and analysis. *Indian journal of medical microbiology*, 26(4), 302.

16. Kembel S.W., Jones E., Kline J., Northcutt D., Stenson J., Womack A.M. and Green J.L. (2012). Architectural design influences the diversity and structure of the built environment microbiome. *The ISME journal*, 6(8), 1469.

17. Toivola M., Alm S., Reponen T., Kolari S. and Nevalainen A. (2002). Personal exposures and microenvironmental concentrations of particles and bioaerosols. *Journal of Environmental Monitoring*, 4(1), 166-174.

18. Mentese S., Arisoy M., Rad A.Y. and Güllü G. (2009). Bacteria and fungi levels in various indoor and outdoor environments in Ankara, Turkey. *Clean–Soil, Air, Water*, 37(6), 487-493.

19. Fung F. and Hughson W.G. (2003). Health effects of indoor fungal bioaerosol exposure. *Applied occupational and environmental hygiene*, 18(7), 535-544.

20. Ohnishi H., Yokoyama A., Hamada H. and Manabe S., Ito R., Watanabe A. and Higaki J. (2002). Humidifier lung: possible contribution of endotoxin-induced lung injury. *Internal medicine*, 41(12), 1179-1182.

21. Wallace L.A., Pellizzari E.D., Hartwell T.D., Davis V., Michael L.C. and Whitmore R.W. (1989). The influence of personal activities on exposure to volatile organic compounds. *Environmental Research*, 50(1), 37-55.

22. Norbäck D., Björnsson E., Janson C., Widström J. and Boman G. (1995). Asthmatic symptoms and volatile organic compounds, formaldehyde, and carbon dioxide in dwellings. *Occupational and environmental medicine*, 52(6), 388-395.

23. Brooks B.O., Utter G.M., DeBroy J.A. and Schimke R.D. (1991). Indoor air pollution: an edifice complex. *Journal of Toxicology: Clinical Toxicology*, 29(3), 315-374.

24. Liu X.P., Niu J.L., Kwok K.C., Wang J.H. and Li B.Z. (2010). Investigation of indoor air pollutant dispersion and cross-contamination around a typical high-rise residential building: wind tunnel tests. *Building and environment*, 45(8), 1769-1778.

25. Evans G.W. and McCoy J.M. (1998). When buildings don't work:The role of architecture in human health. *Journal of Environmental psychology*, 18(1), 85-94.

26. Cao S.J. and Meyers J. (2015). Fast prediction of indoor pollutant dispersion based on reduced-order ventilation models. Tsinghua University Press, *Building Simulation,* 8(4), 415-420.

27. Colton M.D., MacNaughton P., Vallarino J., Kane J., Bennett-Fripp M., Spengler J.D. and Adamkiewicz G. (2014). Indoor air quality in green vs conventional multifamily low-income housing. *Environmental science & technology*, 48(14), 7833-7841.

28. Qian H., Li Y., Seto W.H., Ching P., Ching W.H. and Sun H.Q. (2010). Natural ventilation for reducing airborne infection in hospitals. *Building and Environment*, 45(3), 559-565.

29. Chartier Y. and Pessoa-Silva C.L. (2009). Natural ventilation for infection control in health-care settings. *World Health Organization*.

30. Rotton J. and White S.M. (1996). Air pollution, the sick building syndrome, and social behavior. *Environment international*, 22(1), 53-60.

31. Hagström K., Kosonen R., Heinonen J. and Laine T. (2000). Economic value of high quality indoor air climate. In *Proceedings of the Healthy Buildings,* 1, 671.

32. Nichol K.L., Lind A., Margolis K.L., Murdoch M., McFadden R., Hauge M. and Drake M. (1995). The effectiveness of vaccination against influenza in healthy, working adults. *New England Journal of Medicine*, 333(14), 889-893.

33. Bendrick G.A. (1998). Seasonal variation of grounding rates among B-52H aircrew. *Military medicine*, 163(10), 692-694.

34. Feeney A., North F., Head J., Canner R. and Marmot M. (1998). Socioeconomic and sex differentials in reason for sickness absence from the Whitehall II Study. *Occupational and environmental medicine*, 55(2), 91-98.

35. Knave B., Paulsson H., Floderus B., Gronkvist L., Haggstrom T., Jungeteg G. and Wennberg A. (1991). Incidence of work-related disorders and absenteeism as tools in the implementation of work environment improvements: the Sweden Post strategy. *Ergonomics*, 34(6), 841-848.

36. Teculescu D.B., Sauleau E.A., Massin N., Bohadana A.B., Buhler O., Benamghar L. and Mur J.M. (1998). Sick-building symptoms in office workers in northeastern France: a pilot study. *International archives of occupational and environmental health*, 71(5), 353-356.

37. Mentese S., Rad A.Y., Arısoy M. and Güllü G. (2012). Multiple comparisons of organic, microbial, and fine particulate pollutants in typical indoor environments: diurnal and seasonal variations. *Journal of the Air & Waste Management Association*, 62(12), 1380-1393.

38. Berglund B., Brunekreef B., Knöppe H., Lindvall T., Maroni M., Mølhave L. and Skov P. (1992). Effects of indoor air pollution on human health. *Indoor Air*, 2(1), 2-25.

39. Wallace L.A., Nelson C.J., Highsmith R. and Dunteman G. (1993). Association of personal and workplace characteristics with health, comfort and odor: a survey of 3948 office workers in three buildings. *Indoor Air*, *3*(3), 193-205.

40. Clausen P.A., Wilkins C.K., Wolkoff P. and Nielsen G.D. (2001). Chemical and biological evaluation of a reaction mixture of R-(+)-limonene/ozone: formation of strong airway irritants. *Environment International*, 26(7-8), 511-522.

41. Nazaroff W.W. and Weschler C.J. (2004). Cleaning products and air fresheners: exposure to primary and secondary air pollutants. *Atmospheric Environment*, 38(18), 2841-2865.

42. Cattaneo A., Peruzzo C., Garramone G., Urso P., Ruggeri R., Carrer P. and Cavallo D.M. (2011). Airborne particulate matter and gaseous air pollutants in residential structures in Lodi province, Italy. *Indoor Air*, 21(6), 489-500.

43. Kulshreshtha P. and Khare M. (2011). Indoor exploratory analysis of gaseous pollutants and respirable particulate matter at residential homes of Delhi, India. *Atmospheric Pollution Research*, 2(3), 337-350.

44. Norhidayah A., Chia-Kuang L., Azhar M.K. and Nurulwahida S. (2013). Indoor air quality and sick building syndrome in three selected buildings. *Procedia Engineering*, 53, 93-98.

45. Mentese S. and Tasdibi D. (2017). Assessment of residential exposure to Volatile Organic Compounds (VOCs) and Carbon Dioxide (CO2). *Global Nest Journal*, 19(4), 726-732.

46. Canha N., Lage J., Candeias S., Alves C. and Almeida S. M. (2017). Indoor air quality during sleep under different ventilation patterns. *Atmospheric Pollution Research*, 8(6), 1132-1142.

47. Tham K.W. (2016). Indoor air quality and its effects on humans—A review of challenges and developments in the last 30 years. *Energy and Buildings*, 130, 637-650.

48. Rashid M. and Zimring C. (2008). A review of the empirical literature on the relationships between indoor environment and stress in health care and office settings: Problems and prospects of sharing evidence. *Environment and Behavior*, 40(2), 151-190.