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Indoor Air Pollutant Standards and Potential Impact on Human Health due to Poor Indoor Air Quality in Indian Context

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KEYWORDS

Human Health Effect, Indoor Air Quality, Indoor Air Pollution, Indoor air Pollutants, Indoor Air Pollution Standard.

ABSTRACT:
Human being spent their substantial part of life living indoor. Thus the quality of indoor environment becomes significant to consider in terms of purity of air available for breathing and other parameters i.e. building design, Heating, ventilation, and air Conditioning systems (HVAC), rugs & carpets, paints & polishing, household cleaning appliances, aerosols, insecticides, pesticides, and personal care products & devices, etc. which generates potentially harmful by-products and contributes to indoor environment deterioration directly. Better indoor environment is subject to the quality of thermal comfort i.e. Relative Humidity and Temperature, and the air quality (concentrations of pollutants) inside the buildings. Indoor air quality pertains to the purity of inside air within the building that is essential requirement and equivalent for human comfort. In this article, focus on "required indoor air quality" (RIAQ) as per human comfort, and Indoor Air Quality (IAQ) standards for various indoor air pollutants along with impacts of major indoor pollutants like CO2, Formaldehyde, Radon, and volatile organic compounds, etc in indoor air and on human health have been reported. From literature survey it has been observed that the indoor air quality standards are not available for most indoor air pollutants. Thus, from different research outcomes, and government directories the indoor air pollutant standards are tabulated and presented for a quick understanding & its availability for their permissible limits.

I. INTRODUCTION

Many gas compounds have been recognized which exists in an indoor environment, say, Oxides of Nitrogen (NOx), Sulpher dioxide (SO2), ozone (O3), Carbon mono-oxide (CO), volatile and semi-volatile organic compounds (VOCs), particulate matter (PM), radon and various microorganisms [1]. A few of these pollutants among CO, NOx, CO2, SO2, O3, PM1, PM2.5, and PM10, etc., are mostly found in the inner and outer environment of any building and a few of them are derived from outside of the building [2].

The natures of these air pollutants are biological, organic, inorganic, or radioactive, also. These air pollutants affect human health as per their exposure time, concentration, and toxicity, and it strongly depends upon the degree of health fitness of a person [3-4].

It has been found that due to air pollution episodes; Asthmatics and patients with chronic obstructive pulmonary disease (COPD) symptoms go worst [4]. The indoor CO2 gas concentrations must remain under 700 ppm in comparison with above outdoor concentrations for "occupant satisfaction and comfort" as par (ASHRAE) Standard 62.1-2013. Mostly indoor CO2 gas concentration ranges between 700 ppm to 2000 ppm (3657 mg-3 approximately) but it can increase up to 3000 ppm (5486 mg-3 approximately) due to improper ventilation and use of unvented appliances [5]. Carbon dioxide is an asphyxiant. The indoor CO2 gas to outdoor CO2 gas ratios lies in between 1 - 3 for almost all environmental situations and for significant health problems to occur, exposure to

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an extremely high CO2 concentration (above 30,000 ppm or 54860 mg-3 approximately) should be there. At moderate concentrations, CO2 causes feelings of stuffiness and discomfort, and respiration can be affected a little above 15,000 ppm (27430 mg-3 approximately). Many health effects are observed like headaches, dizziness, and nausea, when a mankind is exposed to 30,000 ppm and above for CO2 gas [6]. These concentrations affect the metabolism of the human body well as due to carbon dioxide continuous exposure this may lead to forming carbonic acid in the body when combines with water, the amount of CO2 expired can cause the variation in human body pH [7]. As per ICMR recent report, 5.50 Lacs people dead due to outdoor air pollution borne cancer and found 7.0 Lacs new cases every year. Developed countries like America, and China have major cases of Cancer per year, and India is third country among the developing countries. Approximately 30-40% rise in Chest cancer cases for non-smoking people, as per ICMR report. The findings of the report evidenced that the Air Pollution is causing severe health effects on living beings [7]. However, it has been observed that there is a lack of standards for some indoor air pollutants and the available set of standards for indoor air pollutants are scattered as per their source of origin. indoor air pollutants, as per USEPA report. A recent study presents the reduction of particulates matter level by 25% when properly ventilated window was used [7-8]. Automotive vehicle's exhaust gas mainly consists of Carbon mono-oxide, carbon dioxide, Oxides of Nitrogen, Water Vapour, etc. Even a slight increase in nitrogen dioxide (NO2) levels may increase the risk of heart and respiratory deaths. Nitrogen dioxide (NO2) increment of 10 micrograms per cubic meter can increase the total deaths by 0.46%, while it can increase the risk of cardiac deaths by about 0.37% and breath-related deaths may increase by 0.47 percent [9].

II. SOURCES OF INDOOR AIR POLLUTION

A. Pollutant Sources

B. Inadequate Ventilation

Indoor sources that release CO, CO2, NOx, SO2 gases, or PM1, PM2.5, and PM10 particles into the indoor environment are the main cause of indoor air quality problems [7-8]. Insufficient & improper designed ventilation increases the indoor pollutant levels due to inadequate quantity of fresh air to dilute emissions from indoor sources as well as obstructing the outflows of

TABLE I. MAJOR INDOOR POLLUTANTS AND EMISSION SOURCE

Pollutant	**Major emission sources**
Allergens	House dust, domestic animals, insects
Asbestos	Fire retardant materials, insulation
Carbon dioxide	Metabolic activity, combustion activities, motor vehicles in garages
Carbon monoxide	Fuel-burning, boilers, stoves, gas or kerosene heaters, tobacco smoke
Formaldehyde	Particleboard, insulation, furnishings
Micro-organisms	People, animals, plants, air conditioning systems
Nitrogen dioxide	Outdoor air, fuel burning, motor vehicles in garages
Organic substances	Adhesives, solvents, building materials, volatilization, combustion, paints, tobacco smoke
Ozone	Photochemical reactions
Particles	Re-suspension, tobacco smoke, combustion products
Polycyclic aromatic hydrocarbons	Fuel combustion, tobacco smoke
Pollens	Outdoor air, trees, grass, weeds, plants
Radon	Soil, building construction materials (concrete, stone)
Fungal	spores Soil, plants, foodstuffs, internal surfaces
Sulphur dioxide	Outdoor air, fuel combustion

(A.P. Jones, Indoor air quality and health, 2002)

Using the ventilated window in an indoor environment resulted in indoor comfort with low energy consumption and concentration reduction of carbon dioxide was achieved by 46% [10]. Further, in an indoor environment the concentration of ultra-fine particles decreased with the distance from the roadway increases [11]. EPA reports that a few parameters like high temperature and humidity levels can moderate the concentrations of some indoor air pollutants.

III. OUTDOOR AIR POLLUTION

Air pollution has been sighted as one of significant and dangerous threat to human health. As per World Health Organization (WHO) report that the 99% of the world's population breathing unhealthy air. The risks associated with air pollution are similar to those caused by smoking tobacco. Indeed, exposure to air pollution can lead to

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cancer, stroke, respiratory, cardiovascular diseases and other health issues.

Air pollution is now estimated to cause nearly seven million deaths per year. This figure is comparable to the excess mortality caused by COVID-19 in 2020 and 2021. Low- and middle-income countries pay the heaviest toll, accounting for 91% of premature deaths related to air pollution.

The degree of importance for any single source depends upon emitted pollutant concentration and their hazardousness. In a few cases, the maintenance of the source, i.e. device being used, becomes significant. For example, an improperly maintained gas stove releases relatively more carbon monoxide than the properly maintained one [13]. Sources, like - building materials, construction-related equipment or items and products like air conditioners, air fresheners, etc. can release pollutants more or less continuously. On the other hand, the sources which are related to smoking, cleaning, redecorating activities, or doing hobbies release pollutants intermittently. Improperly handled products malfunctioned products, obsolete products which are technically outdated can release higher and sometimes dangerous levels of pollutants in the indoor environment [13].

TABLE II. AVERAGES CONCENTRATION OF VARIOUS AIR POLLUTANTS EMITTED BY THE COMBUSTION OF DIFFERENT FUELS

Fuel	Dung cake	Wood	Kerosene	Mix fuel	LPG	PNG
PM 10 µg/m3	6,804.20	4,427.00	3,407.70	3,373.40	2,409.50	1,976.50
PM 2.5 µg/m3	5,142.20	3,300.70	2,412.00	2,606.80	1,741.30	1,744.90
CO µg/m3	21,359.30	6,186.80	5,583.80	10,802.10	7,263.90	987.6
NO2 µg/m3	123.5	111.7	77.7	88.6	107.3	64.1
VOCs ppb	892.2	755.9	384.1	403.4	61.9	24
Benzene ppb	490.7	415.8	211.3	221.9	34	13.2
Carcinogenic PAHs, µg/m3	22.7	27.8	27	7.4	4.1	27.6
Non-carcinogenic PAHs µg/m3	12.8	45.1	101.6	2.5	1.5	13.1

(Gautam, R., Sharma, & Sehgal, 2013)

Due to any obstruction in the inward flow of outdoor air or because of the improper ventilation a little migration of outdoor air indoors, indoor air pollutants can get accumulated to dangerous levels that can cause severe health and comfort problems. If the buildings are built with natural or mechanical ventilation, it will help to minimize the indoor pollutant levels. Hence, it becomes necessary to look for the database of pollutants' limit.

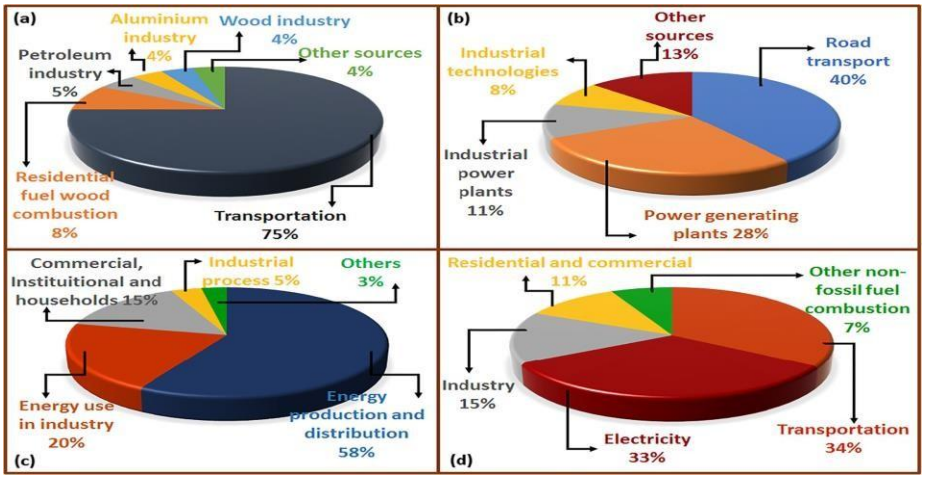

Fig. 1 Graphical representation of various sources and their % contribution towards the emission of air pollutants a. CO, b. NOx , c. SO_2, and d. CO_2 (Courtesy: Premkumar Selvarajan)

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IV. INFILTERATION OF OUTDOOR AIR INSIDE BUILDING

Ambient air inflows indoors through natural ventilation, mechanical ventilation, and infiltration and it may exit through the same mode. The infiltration process involves the outdoor air migration into buildings through different openings i.e. joints, wall cracks, floors, ceilings, window gaps, and door spacing. In the process of natural ventilation, air inflows or outflows through the window and door opening. The air temperature differences between indoors and outdoors and by wind cause the Air circulation related to infiltration and natural ventilation [13-14].

Further, there are several mechanical devices for ventilation like exhaust fans, air handling systems, etc that intermittently remove air from indoor, and fan-duct assembly which continuously removes the indoor air and distributes filtered and conditioned outdoor air throughout the house. The outdoor air exchange rate with indoor air is described because if there's a little infiltration, natural ventilation, or mechanical ventilation, results in low air rate exchange and pollutant levels can increase [10,14,21].

TABLE III. SOURCES OF COMMON VOLATILE ORGANIC COMPOUNDS IN INDOOR AIR

Sources	Examples of typical contaminants
Consumer and commercial products	Aliphatic hydrocarbons (n-decane, branched alkanes), aromatic hydrocarbons (toluene, xylenes), halogenated hydrocarbons (methylene chloride), alcohols, ketones (acetone, methyl ethyl ketone), aldehydes (formaldehyde), esters (alkyl ethoxylate), ethers (glycol ethers), terpenes (limonene, alpha-pinene)
Paints and associated supplies	Aliphatic hydrocarbons (n-hexane, n-heptane), aromatic hydrocarbons (toluene), halogenated hydrocarbons (methylene chloride, propylene dichloride), alcohols, ketones (methyl ethyl ketone), esters (ethyl acetate), ethers (methyl ether, ethyl ether, butyl ether)
Adhesives	Aliphatic hydrocarbons (hexane, heptane), aromatic hydrocarbons, halogenated hydrocarbons, alcohols, amines, ketones (acetone, methyl ethyl ketone), esters (vinyl acetate), ethers
Furnishings and clothing	Aromatic hydrocarbons (styrene, brominated aromatics), halogenated hydrocarbons (vinyl chloride), aldehydes (formaldehyde), ethers, esters
Building materials	Aliphatic hydrocarbons (n-decane, n-dodecane), aromatic hydrocarbons (toluene, styrene, ethylbenzene), halogenated hydrocarbons (vinyl-chloride), aldehydes (formaldehyde), ketones (acetone, butanone), ethers, esters (urethane, ethylacetate).
Combustion appliances	Aliphatic hydrocarbons (propane, butane, isobutane), aldehydes (acetaldehyde, acrolein).
Potable water	Halogenated hydrocarbons (1,1,1-trichloroethane, chloroform, trichloroethane).

TABLE – IV. COMMON INDOOR ALLERGIC AGENTS

Source	Genus	Species	Allergen
Dust-mite	Dermatophagoides	pteronyssinus	*Der p*
	Dermatophagoides	farinae	*Der f*
	Euroglyphus	maynei	*Eur m*
	Hirstia	domicola	*Hir d*
	Lepidoglyphus	destructor	*Lep d*
`	Malayoglyphus	intermedius	*Mal I*
	Malayoglyphus	carmelitus	*Mal C*
	Sturnophagoides	brasiliensis	*Stu b*
Cat	Felis	domesticus	*Fel d*
Dog	Canis	familiaris	*Can f*
Rodent	Mus	musculus	*Mus m*
	Rattus	norvegicus	*Rat n*
Cockroach	Blattela	germanica	*Bla g*
	Periplanetta	americana	*Per a*
Fungi	Alternaria	alternato	*Alt a*
	Aspergillus	fumigatus	*Asp f*
	Cladosporium	herbarium	*Cla h*

Sources: (Jones, 1999)

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V. INDOOR AIR POLLUTION CAUSED HEALTH EFFECTS

In a few Indoor air pollution research it has been reported that the PM2.5 concentration in an indoor environment upto 10 µg/m3 raises the health issues like lung cancer, heart and lung disease of 8%, 6%, and 4%, respectively [15]. Indoor air pollution is found comparatively higher in under developed areas in different states of India and the person working near the fireplaces, who in general are women of different age groups, gets affected by the indoor air pollution. Poorly ventilated kitchens and houses may have relatively higher indoor air pollution. Poor people living in rural regions of the country uses the conventional fuels for cooking and heating purposes rather petroleum products like, LPG, Kerosene stove which are clean sources of energy as these sources does not release harmful gasses.

Energy and Air Pollution report, International Energy Agency (IEA) suggests by 2040, 1.8 billion people additionally will be benefitted through clean cooking facilities which will result in reduction of household emissions in developing countries [13].

TABLE V. ACUTE HEALTH EFFECTS FROM FORMALDEHYDE EXPOSURE

Formaldehyde concentration (ppm)	**Observed health effects**
< 0.05	None reported
0.05-1.5	Neurophysiologic effects
0.05-1.0	Odour threshold limit
0.01-2.0	Irritation of eyes
0.10-25	Irritation of upper airway
5-30	Irritation of lower airway and pulmonary effects
50-100	Pulmonary edema, inflammation, pneumonia
> 100	Coma, death

Sources: (Jones, 1999)

VI. DEATHS CAUSED DUE TO INDOOR AIR POLLUTION

A few institutional reports (Boston-based Health Effects Institute, independent global health, and air pollution research organization) shows an estimate of 846 million people who were exposed to household air pollution in India in 2021 which is 60% of the country's population [16].

World Health Organization report released in 2016, states that nearly 3.8 million people a year die prematurely from illness attributable to the household air pollution caused by any pollutant above these limits will have a serious impact on human health. There are some other organizations also who have set standards for different indoor air pollutants the improper burning of solid fuels and kerosene for cooking and inefficient building structures. About 12% of stillbirths in India could be prevented by providing access to cleaner cooking fuel [6, 17]. Different reasons and their percentage contribution to 3.8 million deaths are 27% due to pneumonia, 18% from stroke, 27% from ischaemic heart disease, 20% from chronic inflammatory lung disease or chronic obstructive pulmonary disease (COPD), and 8% from lung cancer.

In a recent study, developing countries' death rate data were compared, as shown in Table VI & Table VII. It is observed that India among all considered countries India has a greater death count [18].

Figure 2 DEVELOPING COUNTRIES DEATH RATE

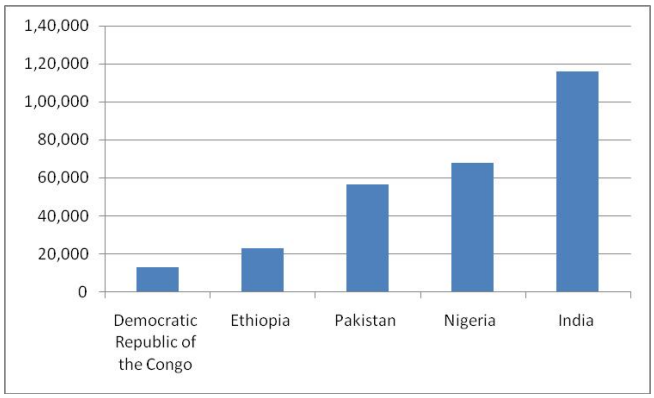

TABLE VI. ADULTS DEATH FROM AIR POLLUTION, 2019

Country	**Death**
India	**6,06,890**
Globally	2.31 million

Source: State of Global Air 2020 Report

VI. INDOOR AIR QUALITY STANDARDS

For some pollutants, there are no safe level sets of exposure. Although threshold limit values vary country-wise and as per organizations. For being able to understand the quality of our indoor air, is it poor or good, researches have been carried out long back and based upon their studies associations like World Health Organization (WHO), National Building Code (NBC), Occupational Safety and Health Administration (OSHA), The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) have set some standards which are like permissible limits beyond which like standards we can use IGBC (Indian Green Building Council), Bureau of Indian Standards (BIS), etc. [19 -20]

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Indoor air quality as governed by multiple parameters lying indoors and their permissible limits have been compared and made available in a tabular form in context with the developing countries and developed countries [17, 21 – 25].

The developing countries like India focus more on its development at various levels which involves extraction of natural resources and apply it at several ends therefore the outdoor air pollution has been the prime concern of researchers and scientific communities. Thus the indoor air quality had caught the less attention so far hence set of standards are lacking in Indian context.

TABLE – VII. SOME INDOOR LOCATION AND POSSIBLE SOURCES OF INDOOR AIR POLLUTANTS

Indoor Location	Pollutant	Sources
Offices, government buildings	Primary: PM, VOCs Additional : CO, NOx, SO2	HVAC systems, carpets, painting & polishing, household cleaners, aerosols, insecticides, pesticides, and personal care products
Parking areas	Primary : PM, CO, NOx, HC Additional : SO2, PAHs,	Vehicular movement
Public places such as restaurants, hotels, libraries, shopping malls (misc. sources)	Primary: PM, VOCs, Nicotine Additional : CO, NOx, SO2	HVAC systems, carpets, painting & polishing, insecticides, pesticides, smoking, constriction activities
Rural households using biomass	Primary: PM, CO, BC Additional : VOCs	Biomass burning for cooking, heating, waste burning. Kerosene burning for lighting,

Sources: (Maroni, Seifert, Lindvall, & T., 1995)

VIII. CONCLUSIONS & FUTURE SCOPE

In India, the clean cooking initiatives of pollution-free cooking started providing ease access to LPG, better cooking stoves which is modified and helps to minimize the harmful gas emission, and biogas plants to the rural residents, especially the people with less eminities. Through different literature it has been observed that the "Clean Air Act" offers broad opportunities for public participation and encourages open access to data about emissions and concentrations of pollution in the air. In the presented work one of important factors responsible for poor Indoor air quality in India is lack of a strong policy and regulation; whereas several other factors contribute to extreme levels of pollution not seen in the United States. There are pollution control laws in India, but enforcement has been lax for fear of alienating critical voting blocs. While the causes of the extreme pollution are well understood, we must impose the rules to be followed. India is committed to the Paris Climate Accord. India's two-thirds power is generated from the conventional source of energy which is coal powered plants and heavily polluting in nature but India aims for a target of 40 percent renewable energy by 2030, according to CNN. It has been investigated and reported that fuel and biomass burning, fuel adulteration, traffic congestion, greenhouse gas emissions, results in climate change and pollution, through atmospheric stagnation, temperature alteration increases in particulate matter, and ground-level ozone formation, which are severe and pollution causing sources in India. Based on the review work, it has been suggested that the standards for parameters whose permissible limits are not defined yet, needs to be finalized and an improvement in outdoor air quality will equally help in Improving Indoor Air Quality. Also, Individuals can improve indoor air quality with the help of suggested methods. The overall concentration of any indoor pollutant must be within the permissible range as per Table IX. It is suggested that to focus on emissions monitoring of six common air pollutants like fine and coarse particulate matter (PM10 and PM2.5), sulfur dioxide (SO2), nitrogen oxides (NOX), and volatile organic compounds (VOCs), carbon monoxide (CO), and lead (Pb). The present work recommends to pay attention for improving the air quality through the "Air (Prevention and Control of Pollution) Act, 1981", through regulation, and by working across all levels of government, including the WHO, EPA, states, tribes, and local governments. Use of Green Buildings can be thought to save energy, reduce waste and energy emissions.

Table – IX Indoor Air Quality Standards for various indoor air pollutants

Indoor Air Quality Standards							
Developed Countries			Developing Countries				
	United States	Japan	India				
Indoor Pollutants/ Contaminants	Concentration						
	ANSI/ASHRAE Standard 62-2001		NBC 2016	ASHRAE	WHO	OSHA	CPCB
Ozone	0.05 ppm, (100 µg/m3)				7 mg/m3 for 24-hours		180 µg/m3
Formaldehyde	0.2–0.5 ppm, (120 µg/m3)				0.1 mg/m3 30-minute exposure		
Carbon monoxide	1-100 mg/m3 (>30 mg/m3 Concentration of concern)	10 ppm (11 mg/m3)	20 mg/m3	9 ppm (8 hours)	10 mg/m3	50 ppm (8 hours)	4 µg/m3 1 hour
Tobacco smoke Respirable particulates	0.05-0.7 mg/m3	0.15 mg/m3					
Carbon dioxide	4.5 g/m3	1,000 ppm (1,800 mg/m3)	–	1000 ppm	–	5000 ppm	
PM 10	150 µg/m3 24 hours averaging		–		50 µg/m3	15 mg/m3	
PM 2.5	25 µg/m3, based on 24-hours averaging		–	–	25 µg/m3	5 mg/m3	60 µg/m3, 24 hours averaging
SO2	Primary, 1-hour, 75 ppb, 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years		80 µg/m3	–	20 µg/m3	5 ppm	80 µg/m3 24-hour Averaging time
	Secondary, 3 hours, 0.5 ppm, Not to be exceeded more than once per year					(8 hours)	
NO2	100 ppb at 1-hour standard		–	–	40 µg/m3 (Annual)	5 ppm (8-hours)	80 µg/m3 24-hour Averaging time
Polycyclic aromatic hydrocarbons			1800 µg/m3	–	8.7 × 10–5 per ng/m3	–	

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