Supplementary Material: SA

Summary of 87 studies on indoor VOCs in hospitals

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
1	Anesthetic drugs, pharmaceutical products, laboratory chemicals, cleaning compounds, sterilization processes, and dust and biological contaminants	- Hospital wards: 455 ± 389.5 ppb - Below OSHA/ACGIH limits, but associated with significant respiratory symptoms	Phocheck Tiger VOC Detector (PID, Ion Science, UK)	- Cough, phlegm, wheezing, phlegmatic cough, shortness of breath - Nurses: Phlegm prevalence was 4.61x higher than controls ($p = 0.002$). - Lab technicians: Odds for cough, phlegmatic cough, and wheezing were very high (up to 13.82 x higher)	Veysi et al. (2019); Iran [51]
2	Hall, waiting room, doctor's consultation room (building materials, cleaning products, paints, adhesives, and human activities)	- 0.17 ppm to 3.02 ppm - The guideline value for VOCs is 1.32 ppm (3 mg/m³), established by the German Supreme Health Authorities (2012) - Exceedances occurred only in the consultation room, while other areas were compliant	Aeroqual Series 500 sensors (manufactured by Aeroqual HQ, Avondale, New Zealand)	Irritation (eyes, nose, throat), headaches, hygienic concerns for doctor's consultation room	López et al. (2021); Spain [97]
3	Disinfection chemicals, building materials, personal activities, chemical reactions, outdoor infiltration	Otorhinolaryngology clinic VOCs (312 ppb) were within acceptable levels and did not exceed the reference standard (set in this study)	Portable & passive air quality sensors, 1-min intervals	Respiratory symptoms, allergic rhinitis/asthma, reduced pulmonary function, possible cancer risk (long-term exposure)	Lee et al. (2020); South Korea [61]
4	Resin monomers, adhesives, bleaching solvents (mostly from General Practice Dentistry (GP) and Periodontal Dentistry (PERIO))	674-1374 ppb (all above TEPA (Taiwan EPA) 560 ppb standard)	Hand-carried detector (ppb RAE 30000, USA)	Respiratory infections, skin/eye irritation, occupational risks; all linked to exceeding TEPA standards	Liu et al. (2017); Taiwan [68]
5	Building materials, renovations (newly renovated), indoor combustion (cooking smoke, oil/gas), outdoor sources	- Benzene: Mean 0.057 mg/m³ (cases) vs 0.035 (controls); 9.1% vs 5.3% exceeded 0.11 mg/m³ - Toluene: Mean 0.093 vs 0.035; 31.8% vs 10.7% exceeded 0.20 mg/m³ - Xylene: Mean 0.088 vs 0.041; 20.5% vs 9.3% exceeded 0.20 mg/m³ - Formaldehyde: Mean 0.063 vs 0.074; 15.9% vs 13.3% exceeded 0.10 mg/m³ - TVOCs: Mean 1.131 vs 0.218; 36.4% vs 10.7% exceeded 0.60 mg/m³ - Chinese national indoor air quality standard GB/T 18883–2002 was used	GC-FID and UV–VIS spectrophotometry	- High TVOC exposure (>0.30 mg/m³) increased risk of congenital heart disease (CHD) in offspring - Strongest effect for septal defects (Adjusted Odds Ratio; AOR 18.62). - Synergistic effect with high PM2.5 (AOR 8.99) - Mechanisms: oxidative stress, DNA damage, altered enzymes/hormones, apoptosis, epigenetic changes - Standards exceeded: TVOCs & toluene most frequently above Chinese indoor limits	Sun et al. (2022); China [37]
6	Surgical smoke/plume from electrocautery, drills, vessel sealing instruments, ultrasonic devices	- TVOC near surgical team (cautery): median 5.6 ppm (range 0.5–33 ppm); This was double	CAIR Plus™ Air Quality Monitor (Prana Air, India): electrochemical sensor for formaldehyde,	- Acute: Headaches, eye/nose/throat irritation, rashes, colic - Chronic: Respiratory problems, cardiovascular disease, lung cancer, mutagenic effects	Rao et al. (2023); India [49]

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		anesthesia workstation, 2.6 ppm - Formaldehyde: median 0.8 ppm (up to 5 ppm): WHO guideline 0.1 μg/m³ (30 min); exceeded	TVOC derived via proprietary formula based on formaldehyde	- Benzene: Carcinogenic, no safe level (WHO, US EPA) - Formaldehyde: Causes sensory irritation; WHO 30-min guideline 0.1 μg/m³ exceeded in study - Standards exceeded: WHO (formaldehyde, benzene)	
7	n-Butanol: Likely from adhesives, sealants, and paints used in hospital furnishing	- All measured TVOC concentrations (115–170 ng/L) are below these benchmarks and do not exceed Finnish, Swedish, and German benchmarks guideline values - Individual compounds: n-Butanol: 20–48 ng/L, Acetic acid: 8–21 ng/L, Hexanal: 7–15 ng/L, Hexanoic acid: 7–15 ng/L	SKC Airchek 224-PCXR8 pumps, Stainless steel ATD tubes packed with Tenax TA (200 mg), Perkin-Elmer ATD-400 thermal desorber, GC-MS	Health impacts were negligible	Nyrud et al. (2012); Norway [92]
8	Cleaning solutions and detergents used in hospitals can increase TVOCs. Formaldehyde from medical treatments is also a potential contributor	- Outdoor TVOC 110 ppb - Hospital street TVOC: 180-236 ppb depending on weather (sunny/rainy/cloudy) - Chinese GB 51039–2014 standard threshold for TVOCs: 240 ppb - TVOC levels in hospital street were below standard	VOC sensor (Q-Trak 7575)	Measured TVOC values did not exceed Chinese standards (GB 51039–2014)	Tang et al. (2020); China [38]
9	Office equipment, renovation materials	- Mean concentrations (μg/m³): Benzene 1.03 ± 1.21, Toluene 0.96 ± 1.79, Ethylbenzene 0.78 ± 1.92, Xylene 0.86 ± 0.73 - All BTEX concentrations were below values recommended by the U.S. EPA	Solid Phase Micro Extraction (SPME) with PDMS/CAR fiber –GC/FID	Health concerns remain due to the carcinogenic nature of benzene and irritant effects of BTEX, though this study found no immediate exceedances.	Kheirmand et al. (2014); Iran [52]
10	Indoor air in patient rooms	- TVOC concentrations were below the recommended long-term guideline value of 300 μg/m³ based on European standard	Tenax TA (Perkin-Elmer) tubes (ISO 16017-2 standard), thermal desorption, GC/MS	No direct health risks were reported within this study's results	Sundkvist et al. (2023); Slovakia [96]
11	Antibacterial disinfectants	- indoor formaldehyde concentrations were higher than outdoors and exceeded Taiwan EPA regulation value of 0.08 ppm in some indoor areas - TVOCs did not exceed the Taiwan EPA regulation value of 0.56 ppm	- TVOCs: Detected with ppbRAE 3000 (RAE Systems, Inc., San Jose, CA) portable VOC monitor - Formaldehyde: Detected with Formaldemeter Htv (PPM Technology Ltd., Wales, UK)	- Associated with irritation and linked to the use of disinfectants. Exceeding levels indicate potential respiratory and health risks to patients, workers, and visitors - Both HCHO and TVOC limits are referenced against the Taiwan Environmental Protection Administration (EPA) indoor air quality standards	Shen et al. (2014); Taiwan [69]
12	Cleaning/disinfection (ethanol, isopropanol,	- TVOC in laboratories (2450 μg/m³) exceeded	Adsorbent tubes with activated charcoal	Health impacts were mostly nuisance odors and occasional irritation	Scheepers et al. (2017); Netherlands [91]

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	acetone), pathology labs (xylenes, formaldehyde use)	the German AGÖF guideline (300 μg/m³ for office comfort) and approached levels linked to eye irritation in hospitals (>1200 μg/m³, Japan study) - No exceedance of WHO/EU occupational standards	(NIOSH method 1500) with GC-FID and canister sampling with TD-GC-MS		
13	- Formaldehyde; building materials, furniture, disinfectants/medical supplies - Benzene; Solvent use, disinfectants, cleaning agents - Toluene; Solvents, cleaning materials, paints - m,p-Xylene; Solvents, paints, plastics, hospital maintenance	- Concentration in Hospitals (GM, μg/m³); Formaldehyde 35.8 (95% CI: 16.3–55.4), Benzene 10.4 (95% CI: 4.3–16.4), Toluene 50.1 (95% CI: 22.3–59.3), m,p-Xylene below MDL (not detected/very low) - Formaldehyde, benzene, and toluene exceeded AGÖF indoor guidance values in hospital settings	GC-FID (Thermofisher Trace 1310, methanol extraction), and spectrophotometer for formaldehyde at 580 nm	- Health impacts exceed U.S. EPA cancer risk thresholds for benzene and formaldehyde, especially for children - Formaldehyde; Carcinogen (IARC Group 1); nasopharyngeal cancer, leukemia - Benzene; Carcinogen (IARC Group 1); leukemia, lymphoma	Otgonbyamba et al. (2023); Mongolia [77]
14	- Benzene; outdoor vehicular traffic, poor ventilation, cleaning/detergents, occasional smoking - Formaldehyde; furniture, finishing materials, flooring, wall coverings, plus detergents/cleaning products, intensified by solar exposure & high temperature - Tetrachloroethylene & Trichloroethylene; cleaning/disinfection solvents - Acetaldehyde, Acetone, Styrene, Xylenes, Ethylbenzene; Building materials, furniture, paints, solvents, and cleaning products - Chloroform; by-products of water/disinfection systems	- Benzene; H1 & H2 mean 2.5-3.4 μg/m³; peaks 6 μg/m³. H3 0.7 μg/m³, EU Directive 2008/50/EC annual: 5 μg/m³, exceeded in H1 & H2 - Formaldehyde; H1 mean 8 μg/m³ (higher in summer); H2 10.2 μg/m³; H3 < 8 μg/m³, WHO (2000/2010): 30 μg/m³ annual; ANSES (2011): 10 μg/m³ annual (2022), Exceeded ANSES (10 μg/m³) in H2; below WHO 30 μg/m³ - Tetrachloroethylene; Mostly 5–8 μg/m³; peaks 13.5 μg/m³, Ontario MOE (2012): 11.88 μg/m³ (24h), some peaks exceeded - Trichloroethylene; <0.01–0.7 μg/m³, well below WHO (2000) - Acetaldehyde; 2–12 μg/m³ below ANSES (2011) - Styrene; 8–12 μg/m³ below WHO (2000/2010) - Acetone 2–8 μg/m³ below ANSES (2011) - Xylenes (m,p,o) below IPCS/WHO (1997) - Ethylbenzene <1–2 μg/m³ below IPCS/WHO (1997)	Passive samplers (Radiello®), GC-MS/ HPLC	Carcinogenic risks (Benzene, Formaldehyde, Trichloroethylene), respiratory and neurological effects (Styrene, Xylene, Acetone, Tetrachloroethylene)	Settimo et al. (2019); Italy [87]

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		- Chloroform <0.01 μg/m³ below CICAD-WHO (2004)			
15	Household renovation, indoor painting, new furniture introduction	- Toluene 128.31 μg/m³ - Benzene 6.91 μg/m³ - Xylene 6.41 μg/m³ - Ethylbenzene 4.68 μg/m³	- VOCs: activated charcoal tubes, analyzed by GC-MS/FID - Formaldehyde: visible spectrophotometry (3-methyl-2-benzothiazolinone hydrazine method)	Strongly associated with recurrent childhood asthma, pediatric asthma incidence	Zhang et al. (2023); China [39]
16	Renovation work (waiting area), medical materials and medicines (pharmacy, ER), human occupation (perfume, sweat, belongings)	All indoor areas exceeded WHO guidelines (81-100 ppb); the pharmacy exceeded OSHA's 750 ppb occupational standard	Low-cost device with BME680 and CCS811 sensors, ISO16000-29 VOC detector standard compliant	Sensory irritation (short exposure), headaches, fatigue, respiratory irritation, and long-term nasal cancer risk (per WHO/OSHA standards)	Lasomsri et al. (2018); Thailand [78]
17	Procedural area of endoscopy unit, gastrointestinal gases expelled from patients, use of electrocoagulation devices, and alcohol compounds (ethanol, isopropanol) during esophageal variceal ligation	- Procedural area 1.27-1155.1 ppb - Cleansing/disinfection area 1.4-1084.6 ppb - Recovery area 0.5-115.4 ppb - Background indoor hospital levels 4-70.1 ppb - Exceedances 19.2% of measurement times in procedural area exceeded acceptable level; up to 7.2% poor-quality (>800 ppb)	uHoo portable passive air quality monitoring sensors	- Oxidative stress, decreased pulmonary function, airway inflammation - Exceeding VOC thresholds considered tolerable to poor-quality air; potential risk for healthcare personnel (long-term respiratory and systemic effects)	Bang et al. (2020); Korea [62]
18	- Disinfectants (40%), food (21%), and drugs (11%) as main odor sources in inpatient rooms - Indoor healthcare activities (e.g., hand rubbing with ethanol/isopropanol, repainting after mold removal)	TVOC in inpatient rooms 100-180 ppb are mostly below Chinese standards, but up to 20% of inpatient/corridor sites exceeded limits	VOC sensor Q-Trak 7575 with probe 984	Odor annoyance, discomfort, risk of exposure to disinfection-related alcohols, and potential exposure to formaldehyde from repainting	Tang et al. (2019); China [40]
19	- Cleaning chemicals, air fresheners, and disinfection practices, especially in the ICU wards, human activities (patient occupancy, medical equipment, and furnishings) also contributed, building materials and poor ventilation in unmanned wards also led to accumulation	- Indoor TVOCs generally 100-700 μg/m³, average 282 μg/m³ - ICU ward peak: 617 μg/m³ (exceeded China NAAQS/GB 600 μg/m³ and WHO 300 μg/m³ limits) - 5 hospital areas exceeded WHO's 300 μg/m³ guideline even when below Chinese standard	Wireless integrated sensors (indoor and outdoor)	- VOCs linked to sick building syndrome (SBS) symptoms such as headache, chest tightness, dry eyes, fatigue - Exceeding WHO standards indicates increased risk of respiratory, neurological, and carcinogenic effects in long-term exposure - ICU levels especially concerning since patients are immunocompromised and highly sensitive to airborne chemicals	Zhou et al. (2022); China [41]
20	Dental offices (treatment, sterilization rooms, waiting rooms), general practitioner offices, pharmacies (commercial	Concentration (mean ± SD, range) - Dental offices showed the highest average VOCs; 700 ± 641 ppb	ppbRAE3000 Photoionization Detector (RAE Systems Inc.)	irritation of eyes, nose, throat, and comfort issues, asthma symptoms, respiratory stress	Baudet et al. (2022); France [82]

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	space & storage rooms), elderly care facilities (common rooms & bedrooms)	overall; up to 1274 ± 504 ppb in sterilization rooms during occupancy; peaks up to 3290 ppb - General practitioner Offices; 143 ± 239 ppb (range 0–3460 ppb) - Pharmacies; 233 ± 199 ppb (range up to 8398 ppb in storage rooms) - Elderly care facilities (149 ± 210 ppb (range up to 2600 ppb)) - The main standard used was the German Committee on Indoor Guide Values (safe <150 ppb; >5000 unacceptable)			
21	Crushing and preparation of oral Endoxan (Cyclophosphamide, CPA) tablets in hospital pharmacy	TVOC 7.6-157.7 ng/sampler, no occupational exposure limit for CPA is defined, but IARC (WHO) classifies CPA as Group 1 Carcinogenic to humans	VOC-SD passive air sampler (Sigma-Aldrich), liquid chromatography with UV detection (LC-UV), and LC-MS/MS (Agilent API4000)	Cytotoxic, mutagenic, teratogenic, and carcinogenic, leukopenia, bladder mucosal changes, secondary cancers	Wakui et al. (2013); Japan [56]
22	Medical equipment (UV/ionization devices), disinfectants and cleaning products, biomedical waste, patient care products, plus infiltration of outdoor air	TVOC 0.2 -1.32 ppm; Mean: 0.75 ppm exceeded Leeds' permissible limit (0.5 ppm)	Portable indoor air quality analyzers	Respiratory irritation, allergies, asthma, lung and airway inflammation, headaches, chronic non-cancer and cancer risks	Nandan et al. (2023); India [50]
23	CCU – Fluoroscopy Room, Other Hospital Rooms (ICU, OT, CCU cubicle, isolation, recovery, etc.)	- CCU; TVOC 9.3 ppm exceeds threshold (3 ppm, DOSH 2005 & ENV 1996 guidelines) - HCOH = 0.05 ppm (below 0.1 ppm) - Other Hospital Rooms; TVOC 0-2.8 ppm (within limits), HCOH 0-0.09 ppm (below 0.1 ppm)	Mini RAE 2000 VOC Monitor, ANLOR Compu Flow IAQ Meter, PPM Formal Demeter	Eye, nose, throat irritation; headache, dizziness, nausea; long-term: liver, kidney, lung, CNS damage; some VOCs suspected carcinogens	Seng et al. (2023); Malaysia [58]
24	Indoor activities, human presence, building materials, cleaning products, paints, glues, building materials, furnishing	- TVOCs: Mean 126 μg/m³ (range 15–486); Std = 400 μg/m³ (MOE Korea); 2% exceeded - Formaldehyde: Mean 24 μg/m³ (range 5–126); Std = 100 μg/m³ (WHO & MOE Korea); 2% exceeded - Postnatal care centers: Formaldehyde mean 59 μg/m³; some samples exceeded HQ >1 for children	- Formaldehyde: 2,4-dinitrophenylhydrazine (DNPH) cartridge and MP-S100 pump (SIBATA, Japan), HPLC with UV-VIS detector - TVOCs: Tenax-TA adsorption tubes + MP-S30 air sampler (SIBATA, Japan), thermal desorption, and GC	non-cancer health effects, asthma, allergies, sensory irritation, respiratory issues, neurological impairments, reproductive disorders, and cancer	Hwang et al. (2018); South Korea [63]
25	Plasticizers in PVC materials (medical	- DINP (Diisononyl phthalate): Median	GC–MS after dust sampling from vacuum bags	- Both DINP and DEHP are classified as endocrine-disrupting chemicals (EDCs)	Al_Qasmi et al. (2019); Qatar [60]

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	devices, flooring, furnishings)	19,626 μg/g (94% of total phthalates) - DEHP (Bis(2-ethylhexyl) phthalate): Median 793 μg/g (4%) - Both exceed safety thresholds implied by EU bans/restrictions		- DINP dominates in hospital dust and poses developmental risks, especially for toddlers - DEHP is strongly linked with reproductive and fertility problems	
26	Disinfectants, building materials, equipment, combustion by-products, cleaning agents, Compressed gas cylinders, solvents, construction	- Ethanol 3956 μg/m³ - Limonene 113 μg/m³ - Isopropanol 174 μg/m³ - Acetone 82.3 μg/m³ - Acrolein 18.1 μg/m³ - Toluene 16.5 μg/m³ - Acetaldehyde 16.2 μg/m³ - Formaldehyde 14.8 μg/m³ - m-, p-Xylene 10.6 μg/m³ - Propanol 24.9 μg/m³ - Ethylbenzene 6.6 μg/m³ - o-Xylene 6.2 μg/m³ - Phenol 5.9 μg/m³ - Benzene 5.1 μg/m³ - Hospital measurements of formaldehyde, acetaldehyde, ethanol, isopropanol exceeded of Cairo consensus	VOC measured in air-phase (hospital: Bessonneau et al. 2013); Modelled partitioning with Henry's Law	- All disrupt embryo viability via oxidative stress, DNA/protein damage, or toxic overload - Acrolein is the most embryo-lethal; formaldehyde causes DNA mutations; ethanol/isopropanol burden culture media at very high levels	Fox et al. (2023); French and others [20]
27	Glass cleaner, general-purpose cleaner, bathroom cleaner	-TVOC (Total VOCs): 0.02-6.49 ppm (10-min avg); peaks up to 11 ppm in small, unventilated bathrooms - 2-Butoxyethanol (2-BE): 0.3-21 ppm across tasks; highest during sink cleaning with general-purpose cleaner; exceeds California REL - Ammonia 0.01-2.8 ppm; well below OSHA PEL	Direct Reading Instrument (PID, GrayWolf TVOC-TG502), thermal desorption tubes, GC/MS	Asthma, irritation, headache	Bello et al. (2020); USA [105]
28	Indoor hospital activities & building material	TVOCs: All floors < 2 ppm (range 0.54–1.87 ppm; Below Taiwan EPA threshold of 3 ppm for hospitals (compliant)	AreaRAE IAQ (PGM-5210) TVOC sensor (accuracy 0.1 ppm)	cause irritation, headache, fatigue; no exceedance found	Wang et al. (2012); Taiwan [70]
29	Central lab waiting room, central lab rooms (staff), polyclinic waiting room, geriatrics polyclinic (<50 patients), nephrology polyclinic (51–500 patients), cardiology polyclinic (>500 patients), inpatient geriatrics rooms, inpatient nephrology	VOC Level (ppm) - Central lab waiting room; Mean 1.07 (Max 2.17) exceeded ECA-IAQ "discomfort range" (1.06–8.86 ppm); EPA/WHO 3 ppm limit not exceeded - Central lab rooms (staff); 0.14–0.58; below	IAQ RAE monitor with Photo-Ionization Detector (PID)	Discomfort; prolonged exposure to TVOCs linked to irritation, headaches, neurological symptoms	Erdoğan et al. (2010); Turkey [103]

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	rooms, inpatient cardiology rooms	discomfort/WHO/EPA limits - Polyclinic waiting room; Mean 1.72 (Max 2.55); under WHO/EPA 3 ppm - Cardiology polyclinic; Mean 1.93 (Max 2.36) - Geriatrics polyclinic; 0.39; Below limits - Nephrology polyclinic; 0.65 (Max 0.95); Below limits - Inpatient geriatrics; Up to 1.26; discomfort zone (>1 ppm) - Inpatient nephrology rooms; 0.26–0.92; below limits - Inpatient cardiology rooms; 0.47–2.07; discomfort zone (>1 ppm)			
30	Surgical smoke generated during laparoscopic surgery using electrocautery systems (both conventional and robotic ORs), smoke accumulates inside patient abdominal cavities and disperses near the surgical table	- Benzene: 477-1266 μg/m³ in abdominal cavity (well above WHO guideline: no safe level; exceeds USEPA RfC 30 μg/m³ and CalEPA REL 3 μg/m³) - Toluene: Up to 632 μg/m³ (exceeds WHO continuous exposure 260 μg/m³; CalEPA chronic REL 300 μg/m³) - Styrene: Up to 216 μg/m³ (close to WHO 260 μg/m³) - Ethylbenzene: Up to 123 μg/m³ (below guideline) - Xylene: Not detected in abdominal cavity, but present at low levels near surgical table/exhaust - Indoor OR air (surgical table & exhaust): concentrations were much lower due to laminar airflow, but benzene still exceeded CalEPA REL in some cases	Tedlar bags connected to trocar (abdominal cavity), low-flow sampling pump MP-Σ30 (SIBATA, Japan) with Tenax TA tubes, Thermal Desorption System (Gerstel TDS2) and GC/MS (Agilent 6890N/5975)	- Benzene: Carcinogenic; causes leukemia, hematologic disorders - Toluene: Neurotoxic, CNS depression, developmental effects - Styrene: Eye, mucous membrane, and nervous system irritation	Choi et al. (2017); South Korea [64]
31	Healthcare activities (hand sanitizer; 2-propanol), Anaesthetic use (ethyl chloride), Building & cleaning materials (acetone, aldehydes, siloxanes, terpenes),	- 2-Propanol: 696.6 μg/m³ (LRI; Leicester Royal Infirmary), linked to hand sanitiser - Ethyl Chloride: 436.5 μg/m³ (LRI), linked to anaesthesia; exceeded US EPA inhalation	Tenax/TA tubes, TD-GC×GC-FID/MS	- Acute effects: eye/nose irritation, headaches, dizziness, unconsciousness (ethyl chloride) - Chronic effects: liver & neurological issues (ethyl chloride), respiratory damage (naphthalene), carcinogenic risk (trichloroethylene)	Riveron et al. (2023); England [13]

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	Outdoor vehicle emissions (hexane, naphthalene)	guideline (100 μg/m³); hazard quotient (HQ) > 1 at LRI 95th percentile (HQ = 2.44) - Acetone: 80 μg/m³, well below US EPA - Hexane: 58 μg/m³, well below US EPA - Naphthalene; LRI: 2.7, GGH (Glenfield General Hospital): 3.1 μg/m³, above US EPA limit in both hospitals - Trichloroethylene; LRI: 1.1; GGH: 4.1 μg/m³, carcinogenic risk at both sites, especially GGH			
32	Dental materials and biomaterials: dentin bonding agents, acrylic resin for restorations, primers, disinfectants, cleaning agents/detergents (elevated VOCs before clinic opening)	- Range: 0.03 – 4.00 mg/m³, mean 0.79 mg/m³, some peaks exceeded Helmis et al. thresholds, more than 75% of values were 0-1 mg/m³ (good range) - Exceedance of Helmis et al. indoor air quality standards (>1 mg/m³ = medium, >3 mg/m³ = poor) observed occasionally	Tongdy TSP-18 IAQ sensors	Respiratory irritation, reduced air quality	Tzoutzas et al. (2021); Greece [84]
33	Indoor hospital environment (Operating Rooms and Other Zones such as wards, offices), sources linked to poor ventilation (split-type AC without fresh air), odors from mold, food, and tobacco	- VOC level measured with Velocicalc 9565 P (TSI). Reported VOC = 0 ppm during monitoring in OR (neurosurgery department) - No exceedance over limits was found - Standards referenced: EN ISO 7730/2006, EN ISO 10551/2002, and ASHRAE 55/2004	Velocicalc 9565 P (TSI)	- While no measured VOC exceedance, poor ventilation led to perceived discomfort (odors, stale air), which can negatively influence health and work performance	Nastase et al. (2014); Romania [95]
34	New hospital building materials, paints, adhesives, furnishings, cleaning agents, floor and wall coverings	New vs. Old Hospital; - Total VOCs (TVOC): 1054 vs 119 μg/m³ - Benzene: 41.94 vs 0.86 μg/m³ - Toluene: 235.15 vs 13.5 μg/m³ - Ethylbenzene: 1.54 vs 0.36 μg/m³ - m,p-Xylene: 5.8 vs 0.68 μg/m³ - o-Xylene: 2.56 vs 0.25 μg/m³ - Styrene: 1.15 vs 0.38 μg/m³ - Formaldehyde: 90.67 vs 18.65 μg/m³ - Acetaldehyde: 12.99 vs 3.8 μg/m³	- VOCs: Tenax-TA sorbent tubes, GC/MS (ISO 16000-6) - Aldehydes: DNPH cartridges, HPLC (ISO 16000-3) - Urinary biomarkers: ELISA for uLTE4, GC-MS for VOC metabolite	- Increased eye dryness & irritation, airway inflammation, VOC metabolites - WHO identifies benzene as carcinogenic even at low concentrations - Formaldehyde above WHO's 100 μg/m³ 30-min guideline - FeNO and uLTE4 changes suggest risk for asthma exacerbation (ATS/ERS biomarkers of airway inflammation)	Kwon et al. (2018); South Korea [65]

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		- Indoor TVOC > WHO guideline of 300 μg/m³ Benzene, toluene, and formaldehyde levels also exceed international indoor air quality standards (WHO, US EPA, EU)			
35	Petrochemicals (from nearby highway, bus terminal), flavors & fragrances (from cleaning agents, furniture, paints, personal care), other compounds (building materials, human emissions, indoor reactions with ozone)	- Most target compounds <0.5 μg/m³ on average - Groups (average ng/m³): Flavors & Fragrances = 1198.62, Petrochemicals = 306.95, Other = 669.68 - Example compounds: Nonanal, Decanal, Geranyl acetone (dominant aldehydes, up to μg/m³ levels); 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (max 8.6 μg/m³)	Dual-bed sorbent tubes (TENAX TA + Carboxen 1000) with Gerstel GSS pumps, thermal Desorption Unit (TDU) + Cooled Injection System (CIS), Comprehensive 2D Gas Chromatography (GC×GC) with High-Resolution TOF Mass Spectrometry (HRMS)	Tiredness, headaches, mucous membrane irritation, skin symptoms (consistent with Sick Building Syndrome), irritants	Veenaas et al. (2020); Sweden [98]
36	Alcohol-based hand rubs, disinfectants, patient care products, cleaning agents, lab products, Building/decoration materials	- Ethanol: mean 928 μg/m³ (max 3956) - Isopropanol: 47.9 μg/m³ (max 174) - Acetone: 22.6 μg/m³ (max 82.3) - 2-Butanone: 8.7 μg/m³ (max 174) - Cyclohexanone: 3.3 μg/m³ (max 20.1) - Ether: mean 75.6 μg/m³ (max 678) - Benzene: 1.6 μg/m³ (max 5.1) - Toluene: 4.7 μg/m³ (max 16.5) - Xylenes: 1.6–3.6 μg/m³ - Ethylbenzene: 1.8 μg/m³ - Styrene: 0.6 μg/m³ - Phenol: 2.3 μg/m³ - All measured concentrations were below regulatory limits (France, EU, USA, WHO)	Active sampling with multisorbent tubes, analyzed by ATD/GC/MS; aldehydes analyzed by HPLC-DNPH	- Carcinogens identified: Benzene (IARC 1), Formaldehyde (IARC 1), Trichloroethylene (IARC 2A), 1,4-Dichlorobenzene (IARC 2B) - Health risks: Mostly irritation, CNS effects, and long-term carcinogenic risks (for benzene & formaldehyde)	Bessonneau et al. (2013); France [9]
37	Building materials (floor and wall materials; e.g., 2-ethyl-1-hexanol, n-undecane), renovations, cleaning & disinfecting products (2-n-butoxyethanol and toluene), solvent & chemical use (Ethylbenzene and toluene)	Concentration Range (μg/m³): - 1-chlorooctane 9–710 (patient/office rooms), up to 1100 at exhaust - 2-ethyl-1-hexanol 4–380; up to 440 at exhaust - 2-n-butoxyethanol 3-530; up to 470 at exhaust	Tenax TA tubes, SKC AirChek pumps; GC-MS with TD (ISO 16000-6:2011)	Irritation of mucous membranes, eye/nose/throat symptoms, dizziness, long-term carcinogenicity concern, odor/nuisance, CNS effects: headache, fatigue, long-term neurotoxic	Rautiainen et al. (2021); Finland [11]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
		- Ethylbenzene 21–100 in offices; 34–53 in patient rooms - n-undecane 6–280 (patient/office); up to 330 at exhaust - Toluene 66–320 in offices; 100–140 in patient rooms - They did not exceed WHO or EU indoor air quality standards for ethylbenzene or toluene. Other compounds were tracers without established indoor standards			
38	Disinfectants, odor-causing sulfur compounds (methanethiol, ethanethiol, DMS, DMDS), aldehydes (hexanal, 2-methylbutanal), and especially formaldehyde	- Formaldehyde tested at 1.0 mg/m³ exposure level with ClO_2 dosages of 5–100 mg/m³, exceed WHO's safe indoor limit	Wet scrubber experimental systems combined with spectrophotometric and chemical analysis methods (e.g., iodometric titration, gas flow spectrophotometer)	Eye/nose/throat irritation, respiratory problems, asthma, human carcinogen	Chen et al. (2020); Taiwan and international studies (USA, Korea, China, etc.) [71]
39	Medicines & medical treatments (e.g., ether, alcohol-based disinfectants, sterilants such as ethanol, isopropanol in cotton balls), pharmacy departments: aromatic hydrocarbons reported, building decoration materials also contribute	Average TVOC concentrations: - Wards: 1.60 ± 1.80 ppm (significantly higher than other areas) - Pharmacy: 0.71 ± 0.29 ppm - Other areas (e.g., clinics, lobby, nurse stations): generally 0.42–0.52 ppm - Exceeding standards: Wards and pharmacy departments reported TVOC levels higher than Taiwan IAQ standards	Real-time VOC monitor: *RAE/PGM-730 (ppbRAE 3000, ProRAE Corporation, San Jose, USA)*	Eye irritation, allergic diseases, cancer risks	Jung et al. (2015); Taiwan [10]
40	New furniture, heating boiler (especially in basements), vehicle exhaust infiltration	2.102 ± 0.74 ppm (below but close to Taiwan EPA threshold of 3 ppm)	ToxiRAE PGM-30 PID (screening), HP 6890 GC/FID (EPA standard method)	Chronic exposure may cause irritation, allergic reactions, respiratory problems	Hsu et al. (2021); Taiwan [72]
41	Chemical cleaning and disinfecting agents (animate/inanimate surfaces), surgical smoke from diathermic/electrocautery devices, inhalational anesthetics (halothane, isoflurane), laboratory sterilization/disinfectants & gases in microbiology lab, proximity to mortuary, car park, ICU	- Main operating theatre 43-146 ppm - Intensive care unit 4 ppm - Accident & Emergency 1 ppm - Microbiology laboratory 1 ppm - Surgical Ward 0-1 ppm - Administrative Dept 1 ppm - All measured values in hospital sites far exceeded WHO limits	Multi-gas monitor	Eye/nose/throat irritation, respiratory tract damage, allergies, asthma, dizziness, nausea, liver/kidney/brain damage, cancer, mutagenicity, immune suppression	Chikwem et al. (2022); Nigeria [102]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
42	Disinfectants, cleaning materials, quick-treatment areas (emergency room, burns unit, pediatric department, men's facility), traffic	- Average indoor VOCs: 0.187 ppm - Result: Hospital VOC levels did not exceed WHO/EPA standards (0.24 ppm)	EntryRAE PGM-3000 Multi-Gas Monitor	Acute and chronic effects (headache, nausea, fatigue, irritation, and increased cancer risk)	El-Sharkawy et al. (2014); Saudi Arabia [76]
43	Patient rooms, medical surgical floors	1,300 - 3100 ppb	Gas Chromatography/Mass Spectrometry (GC/MS) by SGS Galson	Respiratory risks, reduced pulmonary function	Worrilow et al. (2022); USA [106]
44	Dental materials (polymeric materials, essential oils, organic solvents, aldehydes, catalysts), procedures (restorative dentistry with high-speed handpieces, ultrasonic treatment, periodontal cleaning), human activity, combustion byproducts	Low	Air purification devices with HEPA filters and UV/plasma technology	Eye/neck irritation, headache, asthma, high blood pressure, infections, malignancies, respiratory illness, systemic diseases	Tzoutzas et al. (2022); Greece [85]
45	Surgical smoke generated during laparoscopic nephrectomy, caused by electrocautery devices used in coagulation mode (gaseous by-products)	- 1,2-dichloroethane and benzene exceed EPA/NJDEP thresholds, classified as unacceptable cancer risk	Tedlar sampling bags, Tenax sorbent tubes, analyzed with GC/MS under EPA Method TO-1	- Potential long-term cancer risk, bone marrow failure (benzene), neurotoxicity (styrene, toluene, hexane), respiratory irritation - Benzene was notable since its hazard quotient exceeded 1	Choi et al. (2014); South Korea [6]
46	Cleaning, construction, furniture, painting), outdoor contributions (traffic emissions, combustion, haze)	- TVOCs and Formaldehyde: *Not detected (ND)* in all sites, did not exceed standards	- TVOCs: Gas Detector (MiniRAE) - Formaldehyde (CH_2O): Formal Demeter htV	Hazard Quotient (HQ) <1, meaning no health risk	Thongsumrit et al. (2023); Thailand [79]
47	Indoor materials: inferior plywood (formaldehyde), poor paints (benzene, benzaldehyde), unhealthy adhesives (cyclohexanone), Biological origins: exhaled breath (acetaldehyde, acetone, benzaldehyde, indole)	- Formaldehyde 10,000 ppb, benzene 10,000 ppb, cyclohexanone 20,000 ppb, acetone 10,000 ppb, acetaldehyde 1,000 ppb, benzaldehyde 500 ppb, indole 500 ppb, DNT 1,000 ppb, hydrogen sulfide 2,000 ppb - Detection limits were below Chinese Indoor Air Quality Standards (GB/T18883-2002; GB/50325-2020) - Benzene and formaldehyde are noted in WHO guidelines as hazardous even at very low levels - Cyclohexanone may exceed indoor thresholds in practice	- Programmable plasmonic SERS-microfluidic chip (UA, UB units) - UA unit (SERS physisorption) - UC (SERS Ag–S bond chemisorption)	Respiratory irritation, central nervous system effects, and carcinogenic outcomes including lung cancer and leukemia	Yang et al. (2022); China [42]
48	Cleaning activities inside patient rooms (after cleaning the room)	- Average VOCs: 0.40 ppm (all hospitals, 11 case studies); maximum 1.18 ppm; did not exceed standards of Singapore	Gray Wolf's Indoor Air Quality ID.IQ-610	Below international guideline thresholds, but the study notes general SBS symptoms if IAQ deteriorates	Tungjai et al. (2017); Thailand [80]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
49	- PVC flooring, adhesives, fillers (emitting 2-ethyl-1-hexanol, aliphatic hydrocarbons) - Alcohol-based disinfectants & cleaning agents (ethanol, 2-methyl-2-propanol, butanol, limonene) - Pathology labs: xylene, ethylbenzene - Paints, photocopiers, computers, hygiene products, siloxanes	- TVOC in air: avg. 190 μg/m³ (range 2.8–5530 μg/m³) - TVOC in materials: avg. 250 μg/m³g (range 10–5660 μg/m³g) - 2-ethyl-1-hexanol: 1.1 μg/m³ (air) / 310 μg/m³g (material) - Xylenes: up to 3390 μg/m³ in pathology wards - Other detected: decane (3.9 μg/m³), octane (3.7 μg/m³), toluene (3.9 μg/m³), ethylbenzene (up to 850 μg/m³) - WHO (2000) guideline: symptoms associated with TVOC >1200 μg/m³ - Finnish reference values: general indoor TVOC usually <200 μg/m³; some hospital samples exceeded this	Tenax TA sorbent tubes, SKC 222 pumps, analyzed with TD-GC-MS (thermal desorber, GC-MS, Agilent 6890N & 5973N MS, Material samples: Micro-Chamber/Thermal Extractor (μ-CTE, Markes)	- >40% staff: skin irritation/redness - 52%: nasal irritation/runny nose - 37%: hoarse/dry throat; 30%: cough/mucus - 25%: headaches; fatigue common - 2-ethyl-1-hexanol linked to asthma, eye/respiratory irritation; xylenes are hazardous, WHO classifies as toxic with neurotoxic & irritant effects	Rautiainen et al. (2019); Finland [11]
50	Alcohol evaporation from health-care worker hand hygiene practices, hypochlorite cleaning solution used for floor disinfection	- Mean TVOC level: 558.6 ppb; Peak: 750.73 ppb; Lowest: 179.3 ppb - Exceedance: 23.7% of samples failed to meet Taiwan EPA indoor air	ppbRAE Monitor (Model PGM-7600, RAE Systems, San Jose, CA)	Occupational exposure risks exceedance based on Taiwan EPA indoor air quality standard (TVOCs above acceptable levels)	Chung et al. (2015); Taiwan [73]
51	- Surgical operating rooms, women's ward, emergency pharmacy - VOCs are associated with medical activities, disinfectants, pharmaceuticals, building materials	- Most VOC values were at the lowest range (0–1 ppm); majority fell into Level 1 (acceptable) with only 10/550 records reaching Level 2 (moderate) - Exceedance referenced against WHO, US EPA, ISO thresholds for IAQ	IoT-based hardware system with multi-sensors installed and labelled with the UPLPD (Unified Labelling Process) method for classification	Respiratory problems, asthma, fatigue, headaches, skin/eye irritation	Baqer et al. (2022); Iraq [54]
52	Mixture of formaldehyde, benzene, toluene, and xylene (common in building materials, household products, and cigarette smoke)	- Xylene 0.10-2 mg/m³ - Toluene 0.10-2 mg/m³ - Benzene 0.05-1.1 mg/m³ - Formaldehyde 0.05-1.1 mg/m³	- Physical exposure setup (chamber, VOC monitoring), - Behavioral tests (MWM, GS meter), - Biochemical assays (spectrophotometers, fluorescence), - Molecular biology tools (RT-PCR), - Histology microscopy	- Neurobehavioral impacts, oxidative stress, neurotransmitter disruption, NMDA receptor downregulation - Exceeding China IAQS standards was directly linked to neurotoxicity	Wang et al. (2014); China [43]
53	Cleaning products, building materials, furniture, textiles, wood, carpets	Formaldehyde (CH_2O): 0.010–0.021 ppm (below ICOP IAQ 2010 limit: 0.1 ppm); were within standards	- Formaldemeter (ENMET, USA) - TVOC: Aeroqual Series 500	Long-term exposure associated with irritation (eye, skin, respiratory) and cancer risk	Ahmad et al. (2022); Malaysia [59]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
54	Human emissions (breath, skin, personal care products), use of medical/pharmaceutical products for chemotherapy, disinfectants, sterilizers, cleaning products (aldehydes, alcohols, terpenes), infiltration from outdoor traffic emissions	- Background: 0.12–0.37 ppm (isobutylene equivalent) - Daytime peaks (chemo & occupancy hours): 0.60–1.40 ppm - Cited studies show hospital TVOCs often surpass indoor comfort limits, such as the WHO guideline for formaldehyde (0.1 $mg/m^3 \approx 0.08$ ppm)	Corvus IAQ Monitor (Ion Science, UK) – Photo-ionization detector (PID) with Krypton UV lamp (10.6 eV)	Respiratory irritation, sensory irritation, potential cardiovascular and long-term respiratory disease risks	Palmisani et al. (2021); Italy and Spain [88]
55	Building & finishing materials (paints, adhesives, sealants, flooring, furniture), cleaning products and disinfectants (chlorine derivatives, quaternary ammonium salts, phenol, alcohols), medical activities and equipment (plastic infusion bags, blood bags, injectors, films), HVAC systems (air-handling units, poorly maintained ducts, filters), human presence & smoking	- VOCs generally higher indoors than outdoors due to internal hospital sources - Peaks occur after installation/maintenance or cleaning - No single value reported in this paper, but references note exceedances of WHO guidelines (2010) and European/Italian IAQ standards (e.g., formaldehyde, benzene above limits in hospitals)	- Sampling activities recommended (mobile sensors, continuous monitoring, stationary sampling) - VOC analysis requires specialized instruments (not named in detail here, but methods referenced include stationary and passive samplers, IAQ monitors, and filter-based systems)	Respiratory irritation, headaches, neurological effects, increased infection risk, and occupational diseases	Gola et al. (2020); Italy [89]
56	Synthetic wall/furniture materials (plywood, high-density wood, paints, wallpapers, coatings), renovation or new furniture within last 5 years, outdoor sources: heavy traffic roads, chemical factories	- Median benzene: 2.9 $\mu g/m^3$ in cases vs 1.8 $\mu g/m^3$ in controls - Median toluene: 12 $\mu g/m^3$ (cases) vs 9.7 $\mu g/m^3$ (controls) - Median xylene: 6.9 $\mu g/m^3$ (cases ≈ controls) Styrene: higher in cases (median 1.2 $\mu g/m^3$) - Chloroform, carbon tetrachloride, butyl acetate, butyl alcohol, methyl isobutyl ketone significantly higher in cases	Diffusive samplers (passive gas tubes) with activated charcoal, GC-MS, HP 5980 Series II/5971A	- Exceeding standards: based on IARC classifications (Group 1 & 2B carcinogens) - WHO/IARC: Benzene and formaldehyde = Group 1 carcinogens; Styrene, chloroform, carbon tetrachloride, methyl isobutyl ketone = Group 2B (possible human carcinogens)	Gao et al. (2014); China [44]
57	Smells and organic materials in the hospital indoor environment	NA	Awair Omni sensor (low-cost, continuous IEQ monitor)	Acute respiratory responses, headaches, eye/nose/throat irritation	Rantas et al. (2021); USA [107]
58	Mixture of infiltration from outpatient rooms and outdoor air, as the atrium is semi-outdoor and ventilated by air exchange	- TVOC levels measured: 243 ppb (sunny), 266 ppb (cloudy), 180 ppb (rainy) - All values were below the Chinese hospital standard thresholds. No exceedances reported	Standard indoor air quality monitoring instruments (not specified by brand)	TVOC levels were within safety limits	Tang et al. (2019); China [45]
59	Hospital indoor environment (consulting rooms, outpatient areas, emergency department,	- Measured TVOC concentrations ranged 0.010-0.104 mg/m^3 across hospital rooms (highest in Radiology	JD-3002 electronic four-in-one air detector	VOCs are not high enough to impact health	Yao et al. (2022); China [46]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
	radiology, ward, admin rooms, etc.)	department: 0.104 mg/m³) - All values reported were within the standard range, based on the Indoor Air Quality Standard and the Standard for Indoor Environmental Pollution Control of Civil Building Engineering (China)			
60	Cleaning agents, building materials, and hospital equipment (toluene, xylenes, benzene, styrene, n-hexane)	- Total VOCs (TVOCs): 215 ± 100 ppb (open spaces) vs. 458 ± 189 ppb (confined spaces) - Individual VOCs detected: Toluene 15 ppb, Benzene 2 ppb, n-Hexane 2–3 ppb, Xylenes 0.4–0.8 ppb - TVOC >300 ppb in 50% of spaces considered high by WHO	Clean canisters, mass flow controllers (Entech CS1200E), cryogenic concentrator (Entech 7100A), Gas Chromatography (Agilent 6980), Mass Selective Detector (Agilent 5973)	- WHO guideline for indoor benzene is no safe level - Significant associations between TVOCs and SBS-related symptoms (eye, nasal, overall) - VOCs positively related to musculoskeletal, neurological, dermal symptoms - WHO (2010) guidelines: VOCs linked to irritation, allergy, fatigue, decreased lung function in asthmatics - TVOCs >300 ppb linked to throat/respiratory symptoms	Chang et al. (2015); Taiwan [74]
61	Cleaning chemicals, disinfectants, sanitizers (alcohol, chlorhexidine gluconate, aldehydes) used in wards and operation theaters, finishing paints of walls, air fresheners, medical waste bins (especially in Emergency/Pharmacy dept)	- Indoor TVOC: 81-441.7 ppm - Indoor levels exceeded ASHRAE threshold of 3 ppm	Aeroqual 500 series sampler (New Zealand) with photoionization detector for TVOC	- Respiratory irritation, toxic exposure, and additive health burden - Paper highlights severe health consequences from prolonged exposure in crowded, poorly ventilated hospital environments	Zaman et al. (2021); Bangladesh [36]
62	Disinfection products: Mentaback (ethanol, 2-propanol, butanol, glutaraldehyde) in surgery rooms, cleaning/disinfection agents (alkaline compounds: Klorkleen, Corlimp), anesthetic gases: Isoflurane used during surgeries	- TVOCs; Reception area 229-2,524 μg/m³ - TVOCs; Office area 230-3,442 μg/m³ - TVOCs; Treatment area 918-3,672 μg/m³ - Isoflurane: 5.4–6.7 ppm with extractor system; 1.3-1.6 ppm with scavenging system; NIOSH recommended limit: ≤2 ppm; exceedance observed when extractor system used	- TVOC: Indoor air monitoring (portable VOC analyzers, random sampling) - Glutaraldehyde: NIOSH Method 2532 with HPLC-UV - Isoflurane: GC-FID	Eye and nose irritation, reduced comfort, reproductive and neurological risks	Macedo et al. (2018); Portugal [93]
63	- DEHP (a phthalate plasticizer) in indoor environments – emitted from plastics, dust, furnishings, electronic components - In this study: DEHP-d4 aerosol generated using electronic nicotine delivery system (ENDS, e-cigarette–like device)	- Optimized e-liquid contained 0.02% (w/w) DEHP-d4. - Produced aerosols with 25.4 (SD 3.4) mg/m³; ~ 1.4 μg per puff - Predicted exposure concentration (Cexp) = 0.9 mg/m³ over a 10-min exposure, below Swiss OEL = 2 mg/m³	Portable aerosol device (ENDS), Impingers with n-hexane, HPLC, mass spectrometry, Urine & blood analysis	- DEHP known as an endocrine disruptor linked to male reproductive effects, semen quality issues, endometriosis, and respiratory disease - Inhaled DEHP likely reaches alveoli, absorbed into blood, distributed systemically - Exceedance reference: Swiss Occupational Exposure Limit (OEL = 2 mg/m³); exposures in this study remained below OEL	Reale et al. (2023); Switzerland [99]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
		- First participant total weekly dose: 0.45–0.47 mg, still below OEL but detectable in urine			
64	Old office buildings, electronic equipment (computers, photocopiers), consumer products (cleaning agents, insecticides, paper products), construction/renovation materials	Median indoor formaldehyde: 0.36 ppm (IQR 0.28–0.74); maximum up to 2.58 ppm; exceeded Singapore Standard Council 2021, WHO, and East/Southeast Asian IAQ guidelines	- MIRAN SapphIRe portable ambient air analyzer (formaldehyde) - Q-TRAK™ Indoor Air Quality Monitor and VelociCalc® Plus for chemical/thermal parameters	Nasal symptoms, throat symptoms, irritated/runny nose, sore/dry throat, cough, skin irritation (respiratory and dermal SBS)	Surawattanasakul et al. (2022); Thailand [5]
65	cleaning chemicals, floor-cleaning products, air fresheners, human activities	TVOC concentrations measured below detection limit (BDL, <5 ppb) at several sites, but detectable levels (0.17–0.33 ppm warm season; up to 0.20 ppm cold season) occurred in meeting rooms, corridors, BMT waiting area, and ophthalmology rooms; levels remained below the 3 ppm threshold recommended by ASHRAE/European guidelines	PhoCheck Tiger photoionization detection (PID) instruments (Ion Science Ltd., UK)	Eye irritation, headaches, dizziness, respiratory issues, and contribute to Sick Building Syndrome (SBS)	Chamseddine et al. (2019); Lebanon [57]
66	Surgical smoke (formaldehyde, benzene, acrylonitrile, hydrocarbons, nitriles, phenols) generated during various surgical procedures (especially electrocautery, open surgeries with large incisions such as skin graft and laparotomy)	- TVOC (during surgery): Average 1.06 ± 0.99 ppm - Formaldehyde (HCHO): Average 2.28 ± 1.86 ppm; exceeded WHO guideline for formaldehyde 0.1 ppm (30-min avg)	SeeAiR M5-201 air quality monitor	Eye/nose/throat irritation, respiratory problems, carcinogenic risk (formaldehyde, benzene)	Chang et al. (2023); Taiwan [75]
67	Cleaning agents, disinfectants, and sterilization chemicals used in hospital wards and ICUs, patient-care activities and medical procedures, indoor materials (paints, floorings, furnishings)	- Some VOC concentrations exceeded WHO Indoor Air Quality Guidelines and US EPA standards (notably benzene and formaldehyde) - Reported values varied across wards, with higher levels in ICUs and laboratories	Portable air samplers for indoor air collection, GC–MS	- Short-term: Eye irritation, headaches, respiratory irritation, fatigue (noted among healthcare workers) - Long-term: Potential carcinogenic risk (especially benzene and formaldehyde)	Wallenius et al. (2022); Finland [81]
68	Surgical smoke from heat-producing equipment (e.g., electrosurgery, lasers) interacting with tissue, drugs, disinfectants, building materials at curettage, general surgery, eye surgery, neurosurgery, orthopedic, cesarean,	- Benzene 7.42-12.93 μg/m³ - Toluene 5.02-9.99 μg/m³ - Ethylbenzene 1.09-3.01 μg/m³ - Xylene 0.26-0.59 μg/m³ - Total BTEX 14.45-25.71 μg/m³	Passive samplers (diffusive tubes filled with activated charcoal, by Zist-Sephr Beyhagh Co.), GC–MS (Varian CP-3800, Saturn 2200, capillary column)	- Benzene: IARC Group 1 carcinogen. Associated with leukemia, CNS effects. - Other BTEX: linked to skin inflammation, respiratory irritation, eye irritation, brain/CNS disorders	Moslem et al. (2020); Iran [53]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
	laparoscopic, EBT centers (ear, nose, throat)				
69	Hand hygiene & disinfection (alcohol-based hand rubs, surface cleaning), adhesive removers (used in plaster cast rooms and nursing care rooms), disinfectants, sterilization agents, solvents, building materials, (aromatic hydrocarbons), laboratories (solvents and staining in parasitology/mycology labs), cleaning products, plastic medical devices (IV bags, tubing, flooring, coatings, detergents and personal care/cleaning products	- Ethanol (alcohol); median 245.7 μg/m³; peaks >1000 μg/m³; most abundant - Isopropanol (alcohol); median 13.6 μg/m³; max 139 μg/m³; frequently quantified (59–93%) - Acetone (ketone); median 14–19 μg/m³; max 53 μg/m³ - Toluene (aromatic hydrocarbon); median 0.7 μg/m³ (Rennes), 2.1 μg/m³ (Nancy); max ~24 μg/m³ - Formaldehyde (aldehyde); median 3–7 μg/m³; max ~16.7 μg/m³ - Acetaldehyde (aldehyde) median 3–6 μg/m³; max ~12 μg/m³ - Limonene (terpene); typically <1 μg/m³; peaks up to 23–53 μg/m³ during cleaning - Diethyl ether (ether); Median <1.2 μg/m³; peaks 53 μg/m³ (lab/plaster) - Phthalates (SVOCs: DiBP, DEP, DBP, DEHP); DiBP up to 1170 ng/m³; DEP up to 260 ng/m³ - None of the VOC levels exceeded WHO air quality guidelines or EU occupational standards	Thermal desorption–GC/MS for VOCs; DNPH–HPLC for aldehydes; GC/MS/MS for SVOCs	Mainly irritation, CNS effects, and potential long-term carcinogenicity (formaldehyde, acetaldehyde)	Baurès et al. (2018); France [83]
70	- BTEX (Benzene, Toluene, Ethylbenzene, Xylenes): - pharmacy chemicals, solvents, varnishes, detergents, garbage room (hospital waste bins, decomposition gases), poor ventilation in supply & pharmacy rooms (accumulation) - Formaldehyde: disinfectants, ozone sterilization (supply room), off-gassing from building materials, furniture, adhesives - Acetaldehyde: ethanol disinfectants (widely used in hospitals) transformed into acetaldehyde, hospital waste decomposition	- Benzene 4.23-27.2 μg/m³; below China IAQ guideline (110 μg/m³) - Toluene 33.5-264 μg/m³; exceeded China IAQ guideline - Ethylbenzene 8.41-184 μg/m³; below China IAQ guideline - Xylenes 5.06-239 μg/m³; exceeded China IAQ guideline - Formaldehyde 1.03-7.55 μg/m³; exceeded China IAQ guideline - Acetaldehyde 4.56-66.8 μg/m³; No standard - Other carbonyls (butyraldehyde, propionaldehyde, etc.)	- Stainless steel canister, GC/MS (EPA TO-14A) - Formaldehyde; DNPH cartridge + HPLC (EPA TO-11A)	Carcinogenic effects (benzene, formaldehyde, acetaldehyde) and neurotoxic/respiratory impacts (toluene, xylenes, ethylbenzene)	Lü et al. (2010), China [47]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
	- Other carbonyls (e.g., butyraldehyde, propionaldehyde, cyclohexanone, valeraldehyde)	0.07-9.40 μg/m³; No standards			
71	Disinfectants, hydro-alcoholic solutions, cleaning agents, hand sanitizers, dental use/materials, building/decor materials, photocopiers, cleaning products, perfumes in disinfectants, deodorants, pharmacy products, outdoor sources, dental disinfectants (suction units)	- Ethanol (alcohol) ranged 5.4-1085 μg/m³ - Isopropanol (alcohol) ranged 1.3-81.7 μg/m³ - Acetone (ketone) ranged 0.8-118.4 μg/m³ - Formaldehyde ranged 3.4-52.9 μg/m³ - Acetaldehyde ranged 2.1-24.0 μg/m³ - Limonene (Terpene) ranged 0.2-66.7 μg/m³ - Alcohols (ethanol, isopropanol) in dental facilities; aldehydes (formaldehyde) in GP offices/pharmacies - None exceeded WHO acute exposure limits	GC/MS, HPLC/DAD, thermal desorption, 2,4-DNPH cartridges	Mostly irritation, respiratory issues, and long-term risks (formaldehyde carcinogenicity, solvent neurotoxicity)	Baudet et al. (2021); France [112]
72	Sterilizers and cleaning agents in SICU after surgeries, pharmacy chemicals in ED, Paints, furniture, office equipment, and patient emissions (breath/sweating)	In ED Pharmacy: VOC concentrations were moderate, sometimes approaching threshold	MiCS-5524 sensor, integrated into IoT-based ESP32 system	Headaches, exhaustion, irritation of eyes/skin, long-term chronic risks for asthma and nosocomial infections	Baqer et al. (2023); Iraq [55]
73	Outdoor atmospheric inflow rather than indoor sources (e.g., HD machines, dialyzer tubing), nurse breathing	- Benzene (HD room): 13.3-20.1 μg/m³; exceeded standards WHO/US EPA guidelines - Toluene (HD room): 16.1-35.0 μg/m³; below guideline (WHO indoor air) 260 μg/m³)	3M Organic Vapor Monitor #3500, GC/MS	- Benzene is known to cause CNS effects (acute), chronic exposure linked to leukemia & aplastic anemia - Toluene causes CNS depression (dizziness, headaches) - Although concentrations measured are lower than occupational limits, benzene exceeded WHO/EPA environmental safety standards, indicating a potential chronic health risk for patients and staff	Kang et al. (2008); South Korea [66]
74	Cleaning products, building materials, and indoor activities	48.0-661.4 μg/m³; 1.9% bedrooms above Portugal standard of 600 μg/m³	TENAX Tubes (Supelco, Ref. 25054) with SKC personal pumps (0.05 L/min), thermal desorption, Gas Chromatography (Perkin Elmer, ATD 400) per ISO 16000-6	Respiratory infection, asthma exacerbation, headaches	Belo et al. (2019); Portugal [94]
75	Anaesthetic gases, disinfectant, outdoor sources, diathermy	- TVOC 279-46,904 μg/m³ - Anaesthetic compounds (Isoflurane, Sevoflurane) ND-9652 μg/m³; exceeded NIOSH limits - Other aldehydes, oxides, alcohols 107-5268 μg/m³	Tenax-TA tubes, low-flow sampling pumps (SKC); thermal desorption; GC (Varian Star 3400 CX), MS	Irritation (eyes, skin, respiratory), headaches, fatigue, bronchitis; long-term risks: carcinogenicity, genetic damage, reproductive toxicity, neurotoxicity	Dascalaki et al. (2008); Greece [86]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
		- Other VOCs (alkanes, mixed compounds) 31-41,255 μg/m³ - Formaldehyde and Glutaraldehyde (disinfectants) ND-1425; exceeded OSHA limit - Formaldehyde ND-1040 μg/m³; Exceeded OSHA - Glutaraldehyde ND-458 μg/m³; below limits - Aromatic compounds (benzene, toluene, xylene, ethylbenzene, dimethylbenzene) 21-564 μg/m³			
76	- Building materials and office furniture (phenolic/benzene-like compounds) - Molds/fungi (e.g., *Aspergillus fumigatus, A. flavus*) in hospital ventilation systems, wards, and renovation areas	- Fungal VOCs (e.g., dimethyldisulfide, 2-methyl-1-butanol, 1-octen-3-ol, isobutyl ether): 10–100 ng/m³ in contaminated buildings; exceeded Germany of 0.3 ng/m³	GC/MS for VOC analysis (referenced in human exposure and fungal VOC studies)	- Sick Building Syndrome (SBS): Eye/respiratory irritation, inflammation - Nosocomial fungal infections: Outbreaks of aspergillosis, fungemia, pulmonary aspergillosis during construction/renovation	Gedikoglu et al. (2012); Turkey [104]
77	Incubator cleaning with disinfectants (alcohol-based), medical staff/visitors through hand disinfection and presence in NICU	VOC 0.96-5 ppm; exceeding standards of German Federal Environmental Agency limit >25 mg/m³ (~0.4 ppm) for health effects	U-Monitor (U-Earth Biotech Ltd., London, UK)	Headaches, neurotoxicity, asthma symptoms, reduced lung function in children, altered immune T-cell cytokines, lower birth weight, and worse neurocognitive outcomes, prenatal VOC exposure linked to altered immune T-cell cytokines, lower birth weight, and worse neurocognitive outcomes, high risk for premature infants due to immature immune and respiratory systems	Wolf et al. (2020); Germany [7]
78	Plastic medical equipment, especially IV tubing (contributed 89% of cyclohexanone emissions), nasogastric tube, CPAP prongs, nasal cannula, diapers, blankets, sheepskin, pacifier, BP cuff, cardiopulmonary leads	- Cyclohexanone 57–93 μg/m³ - 2-Heptanone 38 ± 19.7 μg/m³ - n-Butyl acetate 8.0 ± 2.1 μg/m³ - Measured values were still below OSHA, ACGIH, NIOSH	Stainless steel canisters, GC/MS analysis, Headspace analysis (ASTM D5116) for individual items, Helium tracer gas dilution (ASTM E741-00) with MGD-2002 multi-gas leak locator	Neonatal risks: possible developmental, cardiovascular, and metabolic impacts	Colareta Ugarte et al. (2014); USA [28]
79	Hand sanitizers & disinfectants, cleaning / sterilizing products, Indoor air / building sources	Low-level	Evacuated canisters (6 L, Silonite-coated) with GC–MS; preconcentration for ppb, loop injection for ppm	Work-related asthma and toxicological concerns (benzene, chloroform, solvents)	LeBouf et al. (2012); USA [108]
80	Incubators themselves (plastic materials, polyurethane foam, bedding), cleaning agents, fragrances, medical/personal care products	- 2-Heptanone 32.54 ± 10.17 ppb - n-Butyl acetate 26.73 ± 7.82 ppb - All incubator levels (ppb) far below workplace limits (ppm), but no neonatal	6 L electropolished stainless steel canisters, EPA TO-15 method with Tekmar AutoCan, agilent 6890 GC / 5973 Mass Spectrometer	CNS effects (sedation, hypoactivity), eye/airway irritation	Prazad et al. (2008); USA [109]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
		standards exist of OSHA/NIOSH/ACGIH			
81	Surgical smoke generated during cervical cancer surgeries using ultrasonic scalpel (laparoscopic hysterectomy)	- TVOC: 2.275 ± 0.339 mg/m³ (exceeds indoor air quality standard China of 0.6 mg/m³) - Benzene: 0.167 ± 0.092 mg/m³ (exceeds IAQ standard China ≤0.11 mg/m³) - Toluene: 0.63 ± 0.118 mg/m³ (exceeds IAQ standard China ≤0.2 mg/m³) - Xylene: 0.268 ± 0.058 mg/m³ (exceeds IAQ standard China≤0.2 mg/m³) - Other detected VOCs: Ethyl benzene, Styrene, Ethyl acetate, Hexane, Butyl acetate, n-Heptane were all within NIOSH RELs	GC–MS after collection into 5L Tedlar gas sampling bags via sorbent adsorption & thermal desorption	- Eye/skin/nose irritation, dizziness, headache, nausea, mutagenicity, carcinogenicity - Benzene: linked to bone marrow abnormalities, leukemia, aplastic anemia, and increased risks of lung, prostate, breast, and kidney cancers - Toluene & Xylene: associated with lung cancer, hematological malignancies, prostate and bladder cancers - General: cytotoxic to airway epithelial (SAEC) and THP-1 cells; time-dependent inhibition of proliferation; higher sensitivity in THP-1 immune cells	Yan et al. (2022); China [48]
82	Electrocautery dissection of porcine tissue producing surgical smoke in operating theatre conditions	- 1,3-Butadiene 19.06 ± 1.54 ppm; exceeds NIOSH/SUVA - Furfural 14.34 ± 2.97 ppm; exceeds NIOSH/SUVA - Benzene 6.21 ± 1.33 ppm; exceeds NIOSH/SUVA - Other compounds (toluene, styrene, ethylbenzene, HCN) were present but not above their respective limits in this study's tests	PTR-MS (Proton-Transfer-Reaction Time-of-Flight Mass Spectrometer), Mobile Smoke Evacuation System (SES, IES 2, ERBE Swiss AG)	Irritants to respiratory tract	Kocher et al. (2019); Switzerland [100]
83	Surgical smoke generated by electrocautery during laparoscopic nephrectomy	- Pre-filter (μg/m³): Benzene 188-203; 1,2-Dichloroethane 175-211; Ethylbenzene 18-35; Styrene 2-7; Acetone 600-887; Hexane 145-205; Toluene 182-211; p-Xylene 10-25 - Post-filter (120 min, μg/m³): Reduced by 85-99% (e.g., Benzene 10–21; 1,2-Dichloroethane 18–31; Ethylbenzene ND-7; Styrene ND-2; Acetone 38-69; Hexane 24-50; Toluene 20-43; p-Xylene ND–5	5-L Tedlar gas-sampling bags, Teflon tubing, GC/MS (EPA Method TO-1) with Tenax® sorbent tubes 83, Filter Device: Prototype multi-layered filter (Activated Carbon Fiber, ULPA, antiviral layers)	- Carcinogens: 1,2-Dichloroethane & Benzene exceeded US EPA & NJDEP DAQ risk thresholds (unacceptable cancer risk pre-filter; reduced but 1,2-Dichloroethane remained slightly above acceptable) - Non-carcinogens: Hazard quotient >1 only for Benzene pre-filter; others reduced to negligible risk (EPA RfC) after filtering	Choi et al. (2018); South Korea [67]
84	Formaldehyde, acetaldehyde, propionaldehyde, isovaleraldehyde, valeraldehyde were	- All VOC levels were below international standards (NIOSH, OSHA, ACGIH)	Radiello passive sampler (BTEX), GC-MS, HPLC	Carcinogenicity (benzene, formaldehyde, acetaldehyde) and asthma/irritation effects, neonatal vulnerability	Santarsiero (2011); Italy [90]

Item	Source	Concentrations and standards	Instruments	Health impacts and standards	References and countries
	directly linked to dental activity (esp. drilling)	- Mean benzene conc. 3.2-3.5 mg/m³ - Mean toluene conc. 5.5-5.6 mg/m³ - Mean ethylbenzene conc 2.1-2.2 mg/m³ - Mean xylenes conc. 4.0-4.2 mg/m³ - Mean methyl Methacrylate conc. 2.8-3.7 mg/m³ - Mean formaldehyde conc. 4.6 mg/m³ - Mean acetaldehyde conc. 7.7-8.2 mg/m³ - Mean propionaldehyde conc. 3.5-3.7 mg/m³ - Mean butyraldehyde conc. 10.3-10.6 mg/m³ - Mean other aldehydes conc. (benzaldehyde, valeraldehyde, isovaleraldehyde) 2-3.5 mg/m³			
85	Renovation on 15th floor (painting/coating with thinner); VOCs migrated via pipeline to 5th floor AHU	- TVOCs: 9.5 ppm (0-10.5) - Urinary hippuric acid: 0.9-2.0 g/gCr - Exceeded ACGIH BEI (1.5 g/gCr)	DirectSense TVOC TG502 (air), HPLC (urine biomarker)	- Irritation (88%), lethargy (80%), loss of concentration (80%), irritability & dizziness (72%) - Effects linked to exceeding ACGIH BEI	Ekpanyaskul (2010); Thailand [2]
86	Surgical smoke generated by electrocautery instruments during live human surgeries in hospital operating rooms	- Ethanol 3.0 ppm - Ethyl acetate 0.0036 ppm - Acetone 0.015 ppm - Fluorene 0.00016 ppm - d-Limonene 0.00050 ppm - α-Pinene 0.00039 ppm - Benzene 0.0011 ppm - n-Hexane 0.0026 ppm - Methylene chloride 0.00060 ppm - Others (toluene, propene, xylenes, butyl acetate, etc.) <0.002 ppm - None exceeded limits; all were <1% of OSHA and Cal/OSHA 8-h PELs	Summa evacuated air canisters with 8-h flow controllers, GC/MS	- Surgical smoke is recognized as containing respiratory irritants, carcinogens, and biologically active particles	Benson et al. (2019); United States [110]
87	Pathology labs, mortuaries, and tissue fixation with formalin solutions, wood-based products, coatings, insulation materials, and building renovations	5 ppb (LOD)-10,300 ppb; exceeded all international standards (France: 8 ppb; Canada: 40 ppb; EU workplace limit: 300 ppb; OSHA action level: 500 ppb)	Ag/AgOx–TiO2 core–shell nanoparticles with smartphone camera read-out	Respiratory irritation, carcinogenic risk	Güntner et al. (2023); Switzerland [101]