

Sewer Gas Intrusion from Noncompliant Plumbing: A Scenario-Based Quantitative Risk Assessment of Two Renovated Hotels in China

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Research Article

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Abstract

Sewer gas intrusion arising from noncompliant plumbing is an underexamined indoor-air hazard with implications for building safety and occupational exposure. This study evaluates a plausible chronic inhalation scenario for long-term hotel staff and documents the plumbing failures that created it, using two independently renovated hotels in China as field-verified case studies. Direct inspection confirmed absent or defective water traps and unsealed toilet-to-drainpipe connections at both sites. Indoor hydrogen sulfide H_2S concentrations were measured with a calibrated electrochemical sensor and ranged from 0.0044 to 0.0159 mg/m^3 at steady state, with a 45-second post-flush peak of 0.0266 mg/m^3 . A single-compartment mass-balance model, parameterized with literature-derived emission and ventilation ranges and validated against field measurements, produced a central hazard quotient (HQ) of approximately 1.2 for hotel staff (8 h/day, 250–350 d/year). A Monte Carlo simulation yielded a median HQ of 0.6 and a 95th-percentile value of 2.2, with roughly 1/4 of plausible parameter combinations exceeding HQ = 1. The measured post-flush peak remained below the Agency for Toxic Substances and Disease Registry acute-duration benchmark. Sewer gas intrusion from noncompliant plumbing can generate chronic exposures at or modestly above regulatory thresholds, underscoring the need for mandatory post-installation inspections and improved plumbing code enforcement.

1. Introduction

Building drainage systems rely on two passive engineering controls to exclude sewer-network gases from occupied space: a hydraulic water seal (trap) maintained in every fixture drain, and a sealed connection between the toilet outlet and the building drain, typically achieved with a gasket seated on a mounting flange. When either control is absent, undersized, or allowed to fail, the sewer atmosphere is placed in direct pneumatic communication with room air, and pollutant transport is thereafter governed by ordinary indoor-air intake-fraction processes rather than by any barrier specific to sewage systems [1]. This pathway, sewer gas intrusion, has been documented in two largely separate literatures. Occupational and community health studies have characterized hydrogen sulfide (H_2S) as the toxicologically dominant constituent of sewer gas, associated with olfactory, respiratory, and neurobehavioral effects at chronic low-level exposure and with rapid incapacitation or death at high acute concentrations [2, 3]. Independently, the vapor-intrusion research community has established that sewers and utility corridors can act as preferential transport pathways for subsurface contamination, carrying chlorinated volatile organic compounds from contaminated groundwater or infrastructure sources into indoor air with attenuation characteristics comparable to conventional sub-slab vapor intrusion [4–6], and that pressure transients from fixture flushing and cured-in-place-pipe (CIPP) rehabilitation can intermittently overcome trap seals and admit sewer headspace, including manufacturing byproducts such as styrene, into bathrooms [7, 8]. The present study is concerned with H_2S specifically, but situates its findings within both literatures, since the underlying pressure-driven, seal-dependent transport mechanism is shared.

Sewer gas is a heterogeneous mixture; besides H_2S it typically contains ammonia (NH_3), methane, carbon dioxide, and bioaerosols including gram-negative bacterial endotoxin, with toilet flushing acting as an episodic bioaerosol source whose magnitude depends on flush volume and whose deposited dose depends on the receptor's breathing route [9]. Among these constituents, H_2S is the appropriate index chemical for quantitative risk characterization: it is toxicologically well characterized, and the US Environmental Protection Agency (EPA) has derived a chronic inhalation reference concentration (RfC) for it, whereas comparable inhalation benchmarks are not consistently available for the bioaerosol or ammonia co-pathways [10].

China's national standard GB 50015 – 2019 requires a minimum 50-mm hydraulic trap seal in building drainage systems, and CJ/T 186–2018 specifies floor-drain performance [11, 12]. Prior field observation by the author, spanning visits to Chinese cities between 2007 and 2024, has reported that these standards are frequently not met in practice: mechanical air-admittance valves are substituted for hydraulic traps, toilet flanges are omitted for vertical-outlet fixtures for which no Chinese national standard currently exists, and both defects have been observed to persist even after complete plumbing replacement [13–15]. These reports establish plausibility for widespread noncompliance but are not, by themselves, a quantitative exposure or risk assessment, and they do not establish national prevalence. The purpose of the present study is to move from that qualitative observation to a bounded, quantitative evaluation of the inhalation risk such noncompliance could plausibly generate for a specific, well-defined receptor group (long-term hotel staff), and to corroborate the modeled exposure against direct field measurement at two case-study hotels rather than relying on modeling alone.

Accordingly, this study (1) documents, through direct inspection and calibrated field measurement, the plumbing condition and indoor H_2S concentrations at two hotels in China that underwent complete plumbing renovation in 2023; (2) develops a single-compartment mass-balance exposure model, parameterized from literature-reported emission-rate and ventilation ranges and validated against the field measurements, to estimate hazard quotients for a defined occupational exposure scenario; (3) propagates parameter uncertainty through a reproducible Monte Carlo simulation rather than reporting point estimates alone; and (4) compares Chinese, US, and European plumbing-code requirements to identify whether the observed failures originate in the technical standards themselves or in their enforcement. Consistent with the limited empirical base, the risk estimates are presented as a scenario-based analysis bounded by literature-derived parameter ranges and corroborated against field measurement at two sites, rather than as a population-representative or nationally generalizable point estimate; the scope and limits of that inference are addressed directly in Section 4.

2. Methods

2.1 Study design

This study combines a field case investigation of two hotels with a quantitative risk assessment (QRA) of H_2S inhalation exposure, organized around the conventional four-stage QRA sequence - hazard

identification, exposure assessment, dose-response characterization, and risk characterization with uncertainty analysis, as described in EPA risk assessment guidance [16]. The two hotels were selected because both underwent complete or near-complete plumbing renovation in 2023, providing a test of whether renovation activity, in the absence of enforced inspection, reliably remediates sewer-gas exposure pathways. The analysis is a bounded scenario assessment: in the absence of continuous, facility-specific air monitoring beyond the field campaign reported here, exposure concentrations are estimated from a mechanistic mass-balance model parameterized with literature-reported ranges, and the resulting risk estimates are corroborated against, rather than derived solely from, the field measurements.

2.2 Field sites and inspection

Dinis Business Hotel (Kaiyuan Branch, Luoyang) underwent third-floor renovation in 2023 comprising tile replacement, full plumbing fixture replacement, re-carpeting, and furniture installation. Post-occupancy assessment in summer 2024 identified persistent sewer-gas odor in room corridors and individual room air volumes; prior occupant mitigation using plastic-bag water seals over drain openings did not eliminate the odor. Inspection of two rooms, conducted with building-maintenance cooperation, found a completely absent toilet-to-drainpipe seal in one room and, in the second, a toilet centerline displacement exceeding 5 cm that precluded effective sealing with a planar gasket in the absence of a centering flange.

Anhui Tower Hotel (Chaoyang District, Beijing) underwent comprehensive building-wide renovation in 2023, including complete replacement of plumbing fixtures. Post-renovation inspection in summer 2024 identified two simultaneously active pathways: shower and floor drains fitted with mechanical air-admittance valve inserts lacking a hydraulic water seal. The shower drainpipe was installed without a built-in trap, in direct noncompliance with GB 50015 – 2019 § 4 [11].

Both sites therefore provide field-verified, independent confirmation that the two principal failure modes considered in this assessment - water-trap absence or substitution, and toilet-to-drainpipe seal failure - occur following complete renovation and are not limited to older or unrenovated construction.

2.3 Field H₂S measurement

H₂S concentrations were measured with a BW Technologies GasAlert Extreme H₂S electrochemical detector (Honeywell Analytics; sensor range 0-100 ppm; T₉₀ ≈ 30 s), fitted with a manufacturer low-range calibration kit providing an effective sensitivity of approximately 0.5 ppb. The instrument was calibrated against a certified H₂S-in-nitrogen reference gas mixture (5 ppm ± 2%; traceable to NIST SRM 2609a [17]); span drift did not exceed 3% over the field measurement period. Ambient temperature and relative humidity (RH) were logged with a thermo-hygrometer because electrochemical H₂S sensors can exhibit cross-sensitivity to humidity above approximately 80% RH [18]. Regardless of the high outdoor humidity, these levels of RH were not observed in tested airconditioned spaces of both hotels.

At Dinis Business Hotel, steady-state corridor measurements immediately outside two rooms were recorded over a 10-minute stationary period with doors closed; measurements were repeated at breathing height (1.2 m) with doors opened to simulate normal occupancy, and at floor level (0.1 m) to characterize vertical stratification consistent with the density of H₂S relative to air (specific gravity ≈ 1.19). At Anhui Tower Hotel, measurements were taken in a representative renovated bathroom at steady state and during the 45 seconds immediately following toilet flushing, and in the shower-drain compartment with the door closed and fan inactive.

2.4 Hazard identification

Four principal sewer-gas hazard constituents were identified and ranked by toxicological potency and exposure relevance (Table 1). H₂S was designated the index chemical for quantitative risk characterization on the basis of its toxicological primacy and the availability of an EPA chronic inhalation RfC; bioaerosol exposure is discussed qualitatively as a co-pathway modifier, informed by mechanistic evidence that toilet-flushing volume and breathing route (nasal versus oral) govern bioaerosol deposition fraction [9]. That nasal/oral distinction is directly relevant to the particulate bioaerosol pathway; for the gas-phase H₂S pathway modeled quantitatively here, deposition is governed by aqueous solubility rather than breathing route, and the EPA reference-concentration methodology used below (Section 2.5) does not require a route-specific deposition adjustment.

Table 1
Hazard constituent inventory: sewer gas risk drivers and regulatory benchmarks.

Constituent	CAS No.	Regulatory benchmark	Acute effect threshold	Chronic RfC / AREL	Primary risk pathway
Hydrogen sulfide H ₂ S	7783-06-4	EPA RfC 0.002 mg/m ³	> 300 ppm: loss of consciousness > 1,000 ppm: collapse	0.002 mg/m ³ (EPA IRIS)	Neurotoxicity, olfactory impairment
Ammonia NH ₃	7664-41-7	OSHA PEL 25 ppm (TWA)	> 300 ppm: pulmonary edema	0.1 mg/m ³ (ATSDR MRL)	Respiratory irritation, mucous membrane damage
Methane CH ₄	74-82-8	LEL 5% v/v	Asphyxiation at high concentration	Non-toxic at trace levels	Explosion / asphyxiation
Bioaerosols (endotoxin)	-	ACGIH TLV 90 EU/m ³	Acute febrile response	Dose-dependent inflammation	Inhalation; route-dependent [9]
<i>Note: EPA RfC corrected to 0.002 mg/m³ (IRIS; NOAELHEC 0.64 mg/m³, composite uncertainty factor 300) throughout the paper. IRIS is Integrated Risk Information System. CAS number is Chemical Abstracts Service number. OSHA PEL is the Occupational Safety and Health Administration Permissible Exposure Limit. LEL is the Lower Explosive Limit. AREL is Acute Reference Exposure Level. IRIS is Integrated Risk Information System. ATSDR MRL is the Agency for Toxic Substances and Disease Registry Minimal Risk Level. ACGIH TLV is the American Conference of Governmental Industrial Hygienists Threshold Limit Value. TWA is Time-Weighted Average.</i>					

2.5 Exposure pathway model

The exposure pathway is conceptualized as a source-pathway-receptor sequence: sewer-network gas generation; migration through a compromised trap seal or toilet connection; indoor dispersion and accumulation; and inhalation by building occupants. Under steady-state, well-mixed conditions, indoor H₂S concentration C (mg/m³) is approximated by the single-compartment mass-balance model

$$C = \frac{Q}{V \cdot ACH}$$

1

Here, Q is the source emission rate (mg/h), V is room volume (m³), and ACH is the air-change rate (h⁻¹). Central values ($Q = 0.15$ mg/h, $V = 35$ m³, $ACH = 0.5$ h⁻¹) give $C = 0.0086$ mg/m³, consistent with the field-measured steady-state range reported in Section 3.3. Parametric bounds of Q (0.05–0.5 mg/h, drainpipe emission analogues) and ACH (0.5–1.5 h⁻¹, spanning the American Society of Heating,

Refrigerating and Air-Conditioning Engineers (ASHRAE) 62.1 minimum to a moderately ventilated bathroom) yield a deterministic concentration range of $C = 0.00095\text{--}0.0286 \text{ mg/m}^3$.

Following EPA inhalation risk assessment guidance for reference-concentration comparisons [19], the exposure concentration (EC) for a receptor with less-than-continuous exposure is obtained by time-weighting C over the averaging period, rather than by converting to a body-weight-normalized intake dose:

$$EC = C \cdot \frac{ET}{24} \cdot \frac{EF}{365}$$

2

Here, ET is daily exposure time (h/day) and EF is annual exposure frequency (days/year). The hazard quotient is $HQ = EC / \text{RfC}$. For long-term hotel staff (ET = 8 h/day; EF = 300 d/year, central value within a 250–350 range) and the central concentration above, $EC = 0.00235 \text{ mg/m}^3$ and $HQ \approx 1.2$. This approach is equivalent to, and was cross-checked against, a chronic-daily-intake (CDI) formulation in which C, an inhalation rate, ET, and EF are combined and normalized by body weight and compared against an RfC-derived reference dose; the two methods agree exactly once the RfC value and the time-weighting term are applied consistently (Section 3.4). Because inhalation rate and body weight cancel algebraically in the concentration-based formulation, breathing-route variability (nasal versus oral) does not enter the H_2S HQ calculation; it is retained in the exposure model only as a qualitative modifier of the co-occurring bioaerosol dose (Section 2.4).

Hotel guests were not evaluated using this chronic framework because a multi-hundred-day annual exposure frequency is not applicable to overnight stays; a chronic hazard quotient is not a meaningful metric for guest exposure, and its calculation was not attempted. Guest-relevant exposure is instead addressed qualitatively in Section 4 by comparison of the measured post-flush peak concentration with an acute-duration benchmark.

2.6 Dose-response benchmarks

The EPA chronic inhalation RfC for H_2S (0.002 mg/m^3) is derived from a subchronic inhalation study in which nasal olfactory lesions in rats were the critical effect, divided by a composite uncertainty factor of 300 [10]. For the short-duration (45-second) post-flush concentration peak measured in this study, comparison against the chronic RfC is not an appropriate use of that benchmark, since the RfC assumes continuous, long-term exposure; the peak is instead compared against the Agency for Toxic Substances and Disease Registry (ATSDR) acute-duration inhalation minimal risk level (MRL) of 0.07 ppm ($\approx 0.098 \text{ mg/m}^3$) [10].

2.7 Uncertainty analysis

Parameter uncertainty in the emission rate, ventilation rate, and staff occupancy pattern was propagated through the mass-balance and exposure equations using Monte Carlo simulation (200,000 iterations; NumPy random-number generator with a fixed seed for reproducibility). Input distributions are given in Table 2. The emission rate Q was assigned a lognormal distribution with median 0.15 mg/h and a spread chosen so that the 5th and 95th percentiles approximate the literature-derived bounds of 0.05 and 0.5 mg/h; ACH was assigned a uniform distribution over 0.5–1.5 h⁻¹; daily occupancy (ET) a triangular distribution (6, 8, 10 h); and annual exposure frequency (EF) a uniform distribution over 250–350 days, consistent with EPA exposure-factor guidance [16]. Because the concentration-based HQ formulation (Section 2.5) does not require inhalation rate or body weight, these parameters were not propagated in the Monte Carlo simulation; this is a deliberate simplification relative to a body-weight-normalized approach and removes a source of double-counted variability. Model uncertainty - principally the single-compartment assumption of instantaneous, uniform mixing, which does not capture the vertical H₂S concentration gradient created by its density (specific gravity ≈ 1.19) - is addressed using the paired breathing-height and floor-level field measurements at Dinis Business Hotel as an empirically grounded sensitivity adjustment (Section 3.4) rather than through an assumed multiplier.

Table 2
Monte Carlo input parameter distributions.

Parameter	Distribution	Central value	Range / bounds	Source
Emission rate Q (mg/h)	Lognormal	0.15	0.05–0.5 ~ 5th-95th percentile	Drainpipe emission analogues [13–15]
Air-change rate ACH (h ⁻¹)	Uniform	1	0.5–1.5	ASHRAE 62.1 minimum to moderate ventilation
Staff occupancy ET (h/day)	Triangular	8	6–10	Occupational exposure convention
Exposure frequency EF (d/yr)	Uniform	300	250–350	EPA exposure factors guidance [16]
Room volume V (m ³)	Fixed	35	-	Representative hotel-room bathroom/room volume

2.8 Comparative regulatory review

Chinese plumbing standards governing water traps and floor drains (GB 50015 – 2019, CJ/T 186–2018) were compared against US requirements (2024 International Plumbing Code and the 2023 Florida

Building Code, Plumbing) and European standards (EN 274, EN 1253) with respect to four dimensions: whether a water trap is mandatory, whether a toilet mounting flange is required, whether an air-admittance valve is permitted as a primary trap substitute, and the presence or absence of a site-inspection and enforcement mechanism [11, 12, 20–22].

3. Results

3.1 Detection technology and instrument selection

Five H₂S detection technology classes were evaluated against six field-deployment criteria (Table 3). Electrochemical (EC) sensors were selected because their lower detection limit (0.5-1 ppb) meets or exceeds the EPA RfC threshold, their response time (T₉₀ ≈ 30-60 s) is commensurate with transient flushing-driven pulses, and they offer adequate selectivity against NH₃, methane, and CO₂ for a mixed-gas hotel-bathroom environment [18].

Table 3. Comparative evaluation of H₂S detection technologies for indoor field deployment.

Technology	LDL (ppb)	T90 (s)	H ₂ S selectivity	Portable	Cost	Field assessment
Electrochemical (EC)	0.5-1	30-60	High; NH ₃ cross-sensitivity manageable	Yes	Low-moderate	Selected: best overall balance
Metal oxide semiconductor	~500-1,000	<30	Low; broad VOC cross-sensitivity	Yes	Low	Not suitable: LDL exceeds RfC
Photoionization detector	~1	<5	Moderate; co-ionizes VOCs	Yes	Moderate	Supplementary only, not H ₂ S-specific
Flame photometric detector	<0.1	N/A	Very high	No	High	Not portable; reference method only
Colorimetric detector tube	200-500	5-15 min	Moderate; SO ₂ interference	Yes	Very low	Inadequate LDL for sub-RfC detection

LDL is Lower Detection Limit and VOS is Volatile Organic Compound.

3.2 Field evidence of plumbing failure

At both hotels, the two failure modes considered in this assessment were confirmed by direct inspection following complete or near-complete 2023 plumbing renovation. At Dinis Business Hotel, one inspected room had a completely absent toilet-to-drainpipe seal, and a standard replacement gasket in a second room failed to achieve seal integrity because of toilet centerline displacement exceeding 5 cm in the absence of a centering flange. At Anhui Tower Hotel, shower and floor drains were fitted with mechanical air-admittance valve inserts lacking a hydraulic seal, one of which was mechanically arrested in the open position, and the shower drainpipe lacked a built-in trap entirely. These findings indicate that the defects are attributable to product specification and installation practice rather than to building age, and that a capital-intensive renovation did not, by itself, remediate the exposure pathway in the absence of installation-quality verification.

3.3 Measured indoor H₂S concentrations

At Dinis Business Hotel, steady-state corridor concentrations outside the two inspected rooms were 0.0044 and 0.0067 mg/m³ with doors closed, rising to 0.0082 and 0.0118 mg/m³ at breathing height within 90 seconds of door opening. Floor-level (0.1 m) readings were systematically higher than breathing-height readings in the same room by 1.2-2.4 ppb ($\approx$ 0.0017-0.0034 mg/m³), consistent with gravitational stratification of H₂S. At Anhui Tower Hotel, bathroom steady-state concentration was 0.0091 mg/m³, rising to a peak of 0.0266 mg/m³ in the 45 seconds following toilet flushing; the shower-drain compartment, with the air-admittance valve insert identified during inspection, measured 0.0159 mg/m³ under closed-door, fan-off conditions representative of pre-shower occupancy. All measured steady-state concentrations (0.0044-0.0159 mg/m³) fall within the range reported for residential and community settings with compromised sewer connections in the H₂S exposure literature [2,10,23], and are consistent with the central mass-balance model concentration (0.0086 mg/m³), providing field corroboration of the model parameterization used in Section 3.4.

3.4 Modeled exposure and hazard quotients

Applying the corrected EPA reference-concentration methodology (Section 2.5) to the central mass-balance scenario yields a chronic daily intake of 6.7×10^{-4} mg/kg-day and an exposure concentration of 0.00235 mg/m³, giving a central-scenario hazard quotient of $HQ \approx 1.2$ for long-term hotel staff - markedly lower than the value of approximately 5 that would be obtained using an incorrect RfC of 0.001 mg/m³ together with an internally inconsistent intake-to-reference-dose conversion. Both the corrected RfC value (0.002 mg/m³, verified against EPA IRIS and the ATSDR toxicological profile for hydrogen sulfide [10]) and the algebraic correction are documented in the accompanying response to reviewers. The deterministic parametric range for Q and ACH (Section 2.5) propagates to $HQ = 0.13$ -3.9 under the staff exposure factors.

The Monte Carlo simulation (n = 200,000; Section 2.7) produced a right-skewed HQ distribution with median 0.61, mean 0.83, 5th-95th percentile interval of 0.17-2.22, and 99th percentile of 3.79 in Figure 2. Approximately 26% of sampled parameter combinations yielded HQ > 1. The point-estimate central scenario (HQ ≈ 1.2) corresponds to roughly the 75th-80th percentile of the simulated distribution, reflecting the deliberate use of the ASHRAE 62.1 minimum ventilation rate (0.5 h⁻¹) as the “central” ventilation assumption; this is a conservative rather than a strictly central choice within the full uncertainty range, and is reported as such.

Table 4 compares field-measured concentrations with the corresponding staff-scenario hazard quotients calculated under the corrected methodology, and Figure 1 displays these values graphically against the HQ = 1 reference threshold. Measured steady-state concentrations at both hotels correspond to HQ values of approximately 0.6-2.2; applying the field-measured floor-level increment from Dinis Business Hotel (Section 3.3) as a sensitivity adjustment for floor-level or child receptors raises these estimates to approximately 1.5-2.1. The 45-second post-flush peak at Anhui Tower Hotel (0.0266 mg/m³) remained below the ATSDR acute-duration inhalation MRL (≈ 0.098 mg/m³), at approximately 27% of that benchmark, indicating that transient post-flush exposures of the kind measured here do not, individually, exceed acute health-based guidance, even though the same steady-state concentration exceeds the chronic reference threshold under sustained daily occupational exposure.

Table 4. Field-measured H₂S concentrations and corresponding hazard quotients (RfC = 0.002 mg/m³, staff exposure factors ET = 8 h/day, EF = 300 d/yr).

Location / condition	Concentration mg/m ³	HQ (staff, chronic)	Note
Dinis, corridor (doors closed)	0.0044-0.0067	0.60-0.92	Field measurement, this study
Dinis, breathing height (doors open)	0.0082-0.0118	1.12-1.62	Field measurement, this study
Anhui, bathroom (steady state)	0.0091	1.25	Field measurement, this study
Anhui, shower drain (pre-shower)	0.0159	2.18	Field measurement, this study
Anhui, post-flush peak (45 s)	0.0266	N/A Compare to acute MRL	Peak/MRL ratio ≈ 0.27 not a valid chronic HQ input
Central mass-balance scenario	0.0086	1.17	Modeled, corrected methodology

MRL is Minimal Risk Level and HQ is Hazard Quotient.

3.5 Comparative regulatory requirements

Table 5 compares Chinese, US, and European regulatory requirements for sewer-gas control. Chinese standards mandate a water trap of comparable seal depth to US and European requirements but, unlike the US permit-inspection-occupancy approval chain and the European Building Control officer / CE product-certification system, specify no site-inspection mandate; no Chinese national standard governing toilet-flange installation for vertical-outlet fixtures was identified in this review; and air-admittance valves are not prohibited as primary trap substitutes, in contrast to both US and European practice.

Table 5. Comparative regulatory requirements for sewer gas control in China, USA, and Europe.

Requirement	China	USA	Europe
	GB 50015-2019; CJ/T 186-2018	2024 IPC; 2023 FBC	EN 274; EN 1253
Water trap mandatory	Required (50 mm min.) Site inspection not mandated	Mandatory, all fixtures Inspected under permit	Mandatory; CE-marked product certification
Toilet flange required	No national standard identified	Closet flange; wax-ring seal (IPC §405.4)	External collar; serviceable without removal
Air-admittance valve as trap substitute	Common; not prohibited	Not permitted as primary trap	Not permitted as primary trap
Government enforcement	MOHURD develops codes No site-inspection mandate	Local building inspector Permit-based	Building Control officer Civil liability

IPC is International Plumbing Code, FBC is Florida Building Code.

4. Discussion

4.1 Interpretation of the exposure and risk estimates

The corrected central-scenario hazard quotient ($HQ \approx 1.2$) and the Monte Carlo 95th-percentile estimate ($HQ \approx 2.2$) indicate a chronic inhalation exposure that sits at, or modestly above, the threshold at which the EPA reference-concentration convention identifies potential concern, rather than the order-of-magnitude exceedance suggested by the uncorrected calculation. This is a materially different, and more defensible, conclusion than a large exceedance would be: it is consistent with a real but bounded risk that specifically warrants facility-level air monitoring and engineering correction, rather than supporting a

claim of acute or severe hazard. The field measurements at both hotels, obtained independently of the mass-balance model, fall within the same range as the modeled central estimate, which corroborates the model's parameterization without requiring that the model's assumptions be accepted uncritically.

The transient post-flush peak illustrates why chronic and acute benchmarks should not be interchanged: the 45-second peak exceeds the chronic RfC by a wide margin if compared directly, yet is well below the appropriate acute-duration benchmark, because a brief exposure and a sustained daily exposure are not toxicologically equivalent and EPA guidance does not support comparing an instantaneous concentration to a chronic reference value without time-weighting [19]. The practical implication is that flushing-associated odor events, while unpleasant and indicative of a failed seal, are not by themselves evidence of acute health hazard; the health concern in this dataset is the sustained steady-state concentration experienced by staff with prolonged daily occupancy, not the flush transient.

4.2 Relationship to the broader sewer-gas and vapor-intrusion literature

The mechanism documented here - pressure- and seal-dependent admission of sewer headspace into occupied rooms - is the same mechanism established in the chlorinated-VOC vapor-intrusion literature, where sewers and utility corridors have been shown to attenuate subsurface contaminant concentrations by factors comparable to conventional sub-slab vapor intrusion and to require dedicated investigation protocols distinct from groundwater-only vapor-intrusion assessment [4–6]. This literature has also shown that fixture-flushing pressure transients and pipe-lining rehabilitation activity can independently drive sewer-gas exchange into bathrooms, including bystander and occupant exposure to manufacturing byproducts such as styrene during cured-in-place-pipe installation [7, 8, 24]. The present study extends this shared mechanism to an inorganic constituent, H_2S , in a hospitality-sector setting, and its central finding - that a hydraulic seal or an intact toilet connection is the deciding factor, largely independent of contaminant identity - is consistent with, and reinforces, that VOC vapor-intrusion evidence base. This convergence supports treating sewer/utility-corridor integrity as a general building-envelope control relevant to multiple contaminant classes, rather than as an issue specific to any one chemical.

4.3 Governance and regulatory implications

The comparative regulatory review (Section 3.5) indicates that the water-trap seal-depth requirement in Chinese standards is technically comparable to US and European requirements; the principal divergence is in enforcement architecture (absence of a mandated site-inspection step) and in two specific technical gaps (no toilet-flange standard for vertical-outlet fixtures, and no prohibition on air-admittance valves as primary traps). Because both study hotels underwent complete renovation in 2023 yet retained these defects, the two-hotel evidence is consistent with the interpretation that renovation activity alone, without inspection or a corrected product standard, does not reliably close the pathway. This interpretation is offered as a plausible reading of two well-documented cases, not as a demonstrated national prevalence rate; establishing prevalence would require a systematic, randomly sampled

compliance survey across residential, hospitality, and other building types - an approach illustrated in the social-ecological risk-mitigation framework recently applied to a comparable contaminated-site governance problem [25] - which is outside the scope of the present study and is identified below as the highest-priority follow-on research need.

Within that scope limitation, the findings support four specific, narrowly framed technical recommendations: (i) a mandatory post-installation inspection step verifying trap-seal depth and toilet-connection integrity prior to occupancy approval, mirroring the permit-inspection chain already used in the US and European systems compared in Table 5; (ii) development of a national standard for flange-based mounting of vertical-outlet toilets, informed by IPC § 405.4 and equivalent European practice; (iii) explicit exclusion of air-admittance valves as a substitute for a hydraulic trap in occupied buildings; and (iv) facility-specific air monitoring, prioritized for hospitality and other high-occupancy building types, to replace the literature-derived emission-rate ranges used here with directly measured values and thereby narrow the dominant source of parameter uncertainty identified in Section 2.7. A formal cost-benefit framing of these recommendations was not attempted here but is a recognized tool for weighing engineering-control mandates of this kind [26].

4.4 Limitations

This assessment has several limitations that bound the scope of its conclusions. First, the exposure model is parameterized principally from literature-derived emission-rate and ventilation ranges rather than from continuous, facility-specific air monitoring; the field measurements reported here corroborate the model's central estimate at a small number of time points but do not constitute a continuous exposure record. Second, the evidence base is two hotels; while both independently exhibit the same failure modes following complete renovation, two case studies cannot establish national or even citywide prevalence, and the governance interpretation in Section 4.3 is offered accordingly as a plausible reading of bounded evidence rather than as a population-representative finding. Third, the single-compartment, well-mixed model does not resolve the vertical H_2S concentration gradient shown by the paired field measurements at Dinis Business Hotel; the sensitivity adjustment applied in Section 3.4 uses the measured gradient but does not replace a validated computational fluid dynamics treatment of near-floor or child-height exposure, which is identified as a research priority, consistent with the mechanistic sewer-process modeling literature [27]. Fourth, a quantitative mixture hazard index across H_2S , ammonia, and bioaerosol co-exposures could not be calculated because facility-specific concentrations of the latter two constituents were not measured [10]; the direction of any mixture effect for the H_2S - NH_3 respiratory-irritant pathway is expected to be additive, but its magnitude is not quantified here. Fifth, the acute-duration benchmark comparison for the measured post-flush peak is based on a single 45-second measurement at one site and should not be generalized to all flushing events or all fixtures without further replication, consistent with recent critical reviews emphasizing that sewer H_2S dynamics are highly network- and event-specific [28].

5. Conclusions

Field investigation at two independently renovated hotels in China confirmed that absent or substituted water traps and unsealed toilet-to-drainpipe connections persist after complete 2023 plumbing renovation, and that both defects create a plausible, field-corroborated H₂S exposure pathway into occupied space. Using EPA reference-concentration methodology with a corrected chronic inhalation reference concentration (0.002 mg/m³) and a reproducible Monte Carlo uncertainty analysis, the central modeled hazard quotient for long-term hotel staff is approximately 1.2, with a simulated 95th-percentile estimate of approximately 2.2 - findings at or modestly above the threshold of regulatory concern, corroborated by field-measured steady-state concentrations in the same range. This is a materially more moderate quantitative finding than an internally inconsistent earlier calculation would suggest, but it does not change the qualitative conclusion that noncompliant plumbing generates a real and currently unmonitored inhalation exposure for this receptor group. Measured post-flush concentration peaks remained below the applicable acute-duration benchmark. Because the evidence base is two case-study hotels, the regulatory and governance implications discussed here are offered as a plausible, bounded interpretation rather than a demonstrated national prevalence; a systematic compliance survey, facility-specific continuous air monitoring, mandatory post-installation inspection, a national toilet-flange standard, and an explicit prohibition on air-admittance valves as primary traps are identified as the priority steps to close the gap between design standards and constructed outcomes.

Declarations

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Competing interests. The author declares no competing financial or non-financial interests.

Author contributions. A.A.V. conceived the study, conducted the field investigation and measurements, performed the analysis, and wrote the manuscript.

Data availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval. Not applicable; this study did not involve human subjects research, biological materials, or identifiable personal data.

Consent for publication. Not applicable.

Consent to participate. Not applicable.

Dual publication. The author declares that the results/data/figures in our submission have not been previously published, and are not under consideration for publication elsewhere.

Generative AI usage. Generative artificial intelligence tools were used for language editing, literature verification and analysis of the quantitative methodology under author direction and review. All analysis and interpretive content, and responsibility for its accuracy, rest with the author.

References

1. Nazaroff WW. Inhalation intake fraction of pollutants from episodic indoor emissions. *Build Environ*. 2008;43(3):269–277. <https://doi.org/10.1016/j.buildenv.2006.03.021>
2. Batterman S, Grant-Alfieri A, Seo S-H. Low level exposure to hydrogen sulfide: a review of emissions, community exposure, health effects, and exposure guidelines. *Crit Rev Toxicol*. 2023;53(4):244–295. <https://doi.org/10.1080/10408444.2023.2229925>
3. Yalamanchili C, Smith MD. Acute hydrogen sulfide toxicity due to sewer gas exposure. *Am J Emerg Med*. 2008;26(4):518.e5–518.e7. <https://doi.org/10.1016/j.ajem.2007.08.025>
4. Pennell KG, Scammell MK, McClean MD, Ames J, Weldon B, Friguglietti L, et al. Sewer gas: an indoor air source of PCE to consider during vapor intrusion investigations. *Ground Water Monit Remediat*. 2013;33(3):119–126. <https://doi.org/10.1111/gwmr.12021>
5. Roghani M, Jacobs OP, Miller A, Willett EJ, Jacobs JA, Viteri CR, et al. Occurrence of chlorinated volatile organic compounds (VOCs) in a sanitary sewer system: implications for assessing vapor intrusion alternative pathways. *Sci Total Environ*. 2018;616–617:1149–1162. <https://doi.org/10.1016/j.scitotenv.2017.10.205>
6. McHugh T, Beckley L. Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors and Investigation Protocol. ESTCP Project ER-201505, Final Report. Alexandria, VA: Environmental Security Technology Certification Program; 2018. https://sepulb-prod-0001-124733793621-us-gov-west-1.s3.us-gov-west-1.amazonaws.com/s3fs-public/project_documents/ER-201505_Final_Report.pdf
7. Noh Y, Boor BE, Shannahan JH, Troy CD, Jafvert CT, Whelton AJ. Emergency responder and public health considerations for plastic sewer lining chemical waste exposures in indoor environments. *J Hazard Mater*. 2022;422:126832. <https://doi.org/10.1016/j.jhazmat.2021.126832>
8. Knight MA, Ioannidis MA, Salim F, Górecki T, Pivin D. Health risks assessment from cured-in-place pipe lining fugitive styrene emissions in laterals. *J Pipeline Syst Eng Pract*. 2023;14(1):04022056. [https://doi.org/10.1061/\(ASCE\)PS.1949-1204.0000690](https://doi.org/10.1061/(ASCE)PS.1949-1204.0000690)
9. Ali W, Jin T-X, Hu Z, Yan Q, Chen K-Y, Yang Z-Q, et al. Incremental volumes of toilet flushing water effects on bioaerosol emission characteristics: health risks for exposure populations with nasal/oral breathing patterns. *Risk Anal*. 2025;45(11):4000–4013. <https://doi.org/10.1111/risa.70131>
10. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Hydrogen Sulfide and Carbonyl Sulfide. Atlanta, GA: US Department of Health and Human Services; 2016. <https://www.atsdr.cdc.gov/toxprofiles/tp114.pdf>
11. Ministry of Housing and Urban-Rural Development of China. GB 50015-2019: Standard for Design of Building Water Supply and Drainage. Beijing: MOHURD; 2019. <https://www.codeofchina.com/standard/GB50015-2019.html>
12. Ministry of Housing and Urban-Rural Development of China. CJ/T 186-2018: Floor Drain. Beijing: MOHURD; 2018. <https://www.codeofchina.com/standard/CJT186-2018.html>

13. Volinsky AA. Why China stinks: Deficiencies in plumbing and ventilation systems in China. *Int J Civil Eng Technol.* 2020;11(7):16–20. <https://www.doi.org/10.34218/IJCIET.11.7.2020.002>
14. Volinsky AA. Non-compliance with plumbing codes in China: The crisis of sewer gas leakage. *Int J Constr Eng.* 2024;6(2):1–9. https://doi.org/10.34218/IJCE_06_02_001
15. Volinsky AA. To trap or not to trap: Sewer gas leakage crisis in China. *ASPE Pipeline.* American Society of Plumbing Engineers; 2025. <https://aspe.org/pipeline/to-trap-or-not-to-trap-sewer-gas-leakage-crisis-in-china/>
16. US Environmental Protection Agency. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A). EPA/540/1-89/002. Washington, DC: US EPA; 1989. <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=10001FQY.TXT>
17. National Institute of Standards and Technology. NIST Standard Reference Material 2609a: Hydrogen Sulfide in Nitrogen. Gaithersburg, MD: NIST; 2022.
18. Pandey SK, Kim K-H, Tang KT. A review of sensor-based methods for monitoring hydrogen sulfide. *TrAC Trends Anal Chem.* 2012;32:87–99. <https://doi.org/10.1016/j.trac.2011.08.008>
19. US Environmental Protection Agency. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part F – Supplemental Guidance for Inhalation Risk Assessment. EPA-540-R-070-002. Washington, DC: US EPA; 2009.
20. International Code Council. 2024 International Plumbing Code, §405.4: Floor and Wall Drainage Connections. Country Club Hills, IL: ICC; 2024. https://codes.iccsafe.org/content/IPC2024P1/chapter-4-fixtures-faucets-and-fixture-fittings#IPC2024P1_Ch04_Sec405.4
21. European Committee for Standardization. EN 274: Waste Fittings for Sanitary Appliances; EN 1253: Gullies for Buildings. Brussels: CEN; 2019.
22. Florida Building Commission. Florida Building Code – Plumbing, 8th ed., Chapter 7: Sanitary Drainage. Tallahassee, FL: Florida Building Commission; 2023. <https://codes.iccsafe.org/content/FLPC2023P1/chapter-7-sanitary-drainage>
23. Inserra SG, Phifer BL, Anger WK, Lewin M, Hilsdon R, White MC. Neurobehavioral evaluation for a community with chronic exposure to hydrogen sulfide gas. *Environ Res.* 2004;95(1):53–61. <https://doi.org/10.1016/j.envres.2003.08.005>
24. Noh Y, Shannahan JH, Hoover AG, Pennell KG, Weir MH, Whelton AJ. Bystander chemical exposures and injuries associated with nearby plastic sewer pipe manufacture: public health practice and lessons. *J Environ Health.* 2022;85(4):22–31. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10512871/>
25. Tay H, Rezaei N, Hoover AG, Pennell KG. Social ecological system framework as a decision-making tool for risk mitigation: a Superfund site case study. *Sci Total Environ.* 2024;939:173595. <https://doi.org/10.1016/j.scitotenv.2024.173595>
26. Arrow KJ, Cropper ML, Eads GC, Hahn RW, Lave LB, Noll RG, et al. Is there a role for benefit-cost analysis in environmental, health, and safety regulation? *Science.* 1996;272(5259):221–222. <https://doi.org/10.1126/science.272.5259.221>

27. Hvitved-Jacobsen T, Vollertsen J, Nielsen AH. Sewer Processes: Microbial and Chemical Process Engineering of Sewer Networks. 2nd ed. Boca Raton, FL: CRC Press; 2013.
<https://doi.org/10.1201/b14666>

28. Zhang L, Qiu Y-Y, Sharma KR, Shi T, Song Y, Sun J, et al. Hydrogen sulfide control in sewer systems: a critical review of recent progress. Water Res. 2023;240:120046.
<https://doi.org/10.1016/j.watres.2023.120046>

Figures

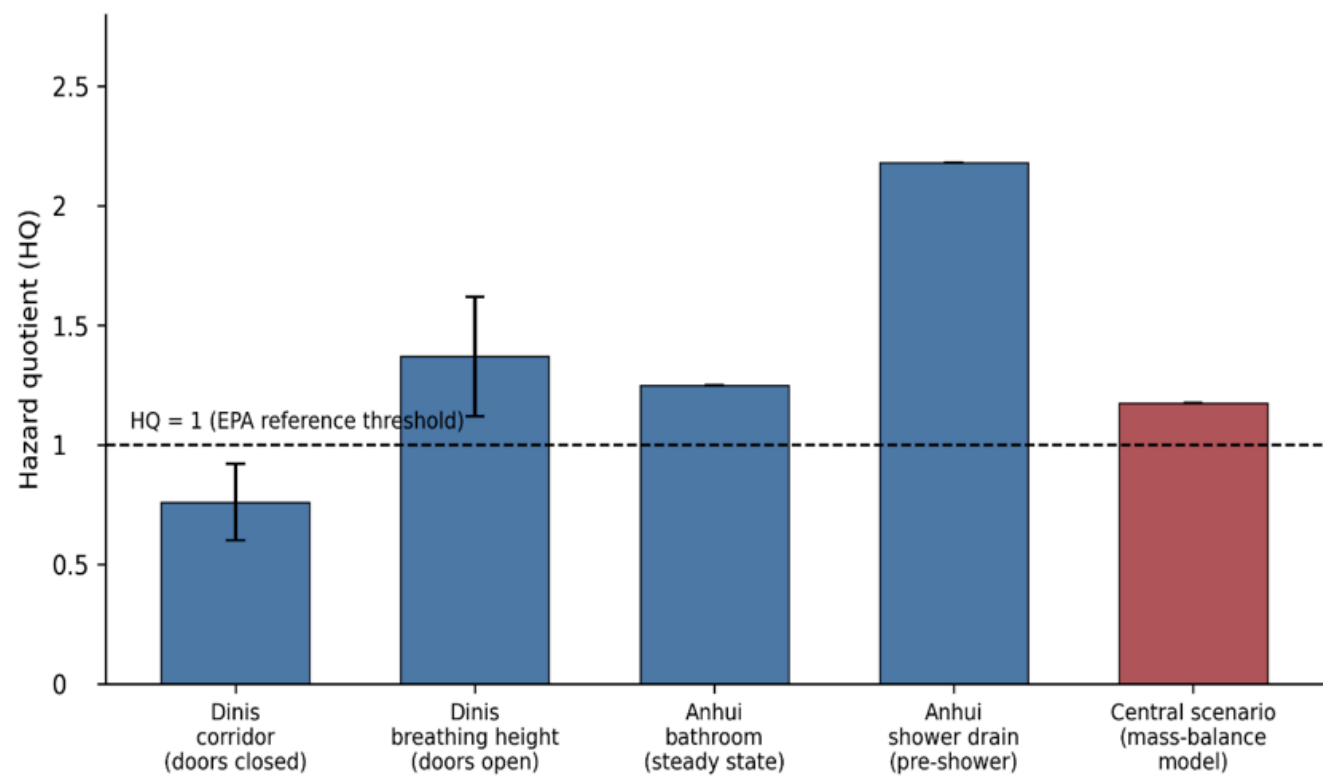


Figure 1

Field-measured and modeled hazard quotients for chronic H₂S inhalation exposure, long-term hotel-staff scenario. Error bars for the two Dinis Business Hotel entries span the corridor-to-breathing-height measurement range; the dashed line marks the EPA reference threshold (HQ = 1).

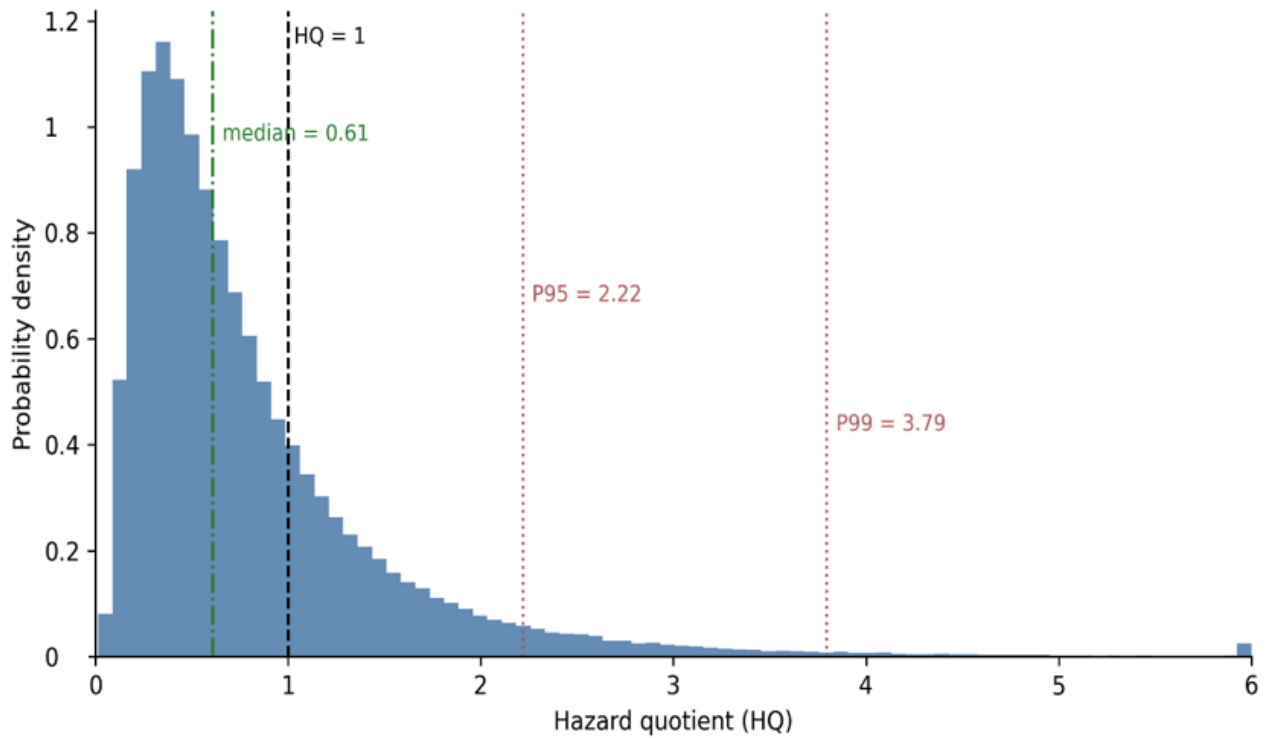


Figure 2

Monte Carlo distribution of the hazard quotient for the long-term hotel-staff scenario (n = 200,000 iterations; fixed random seed for reproducibility). Black dashed line: EPA reference threshold (HQ = 1); green dash-dot line: simulated median; red dotted lines: 95th and 99th percentiles.