Root-Cause Analysis of Stale/Musty Odor in a Dubai Villa:

An Indoor Air Quality Case Study

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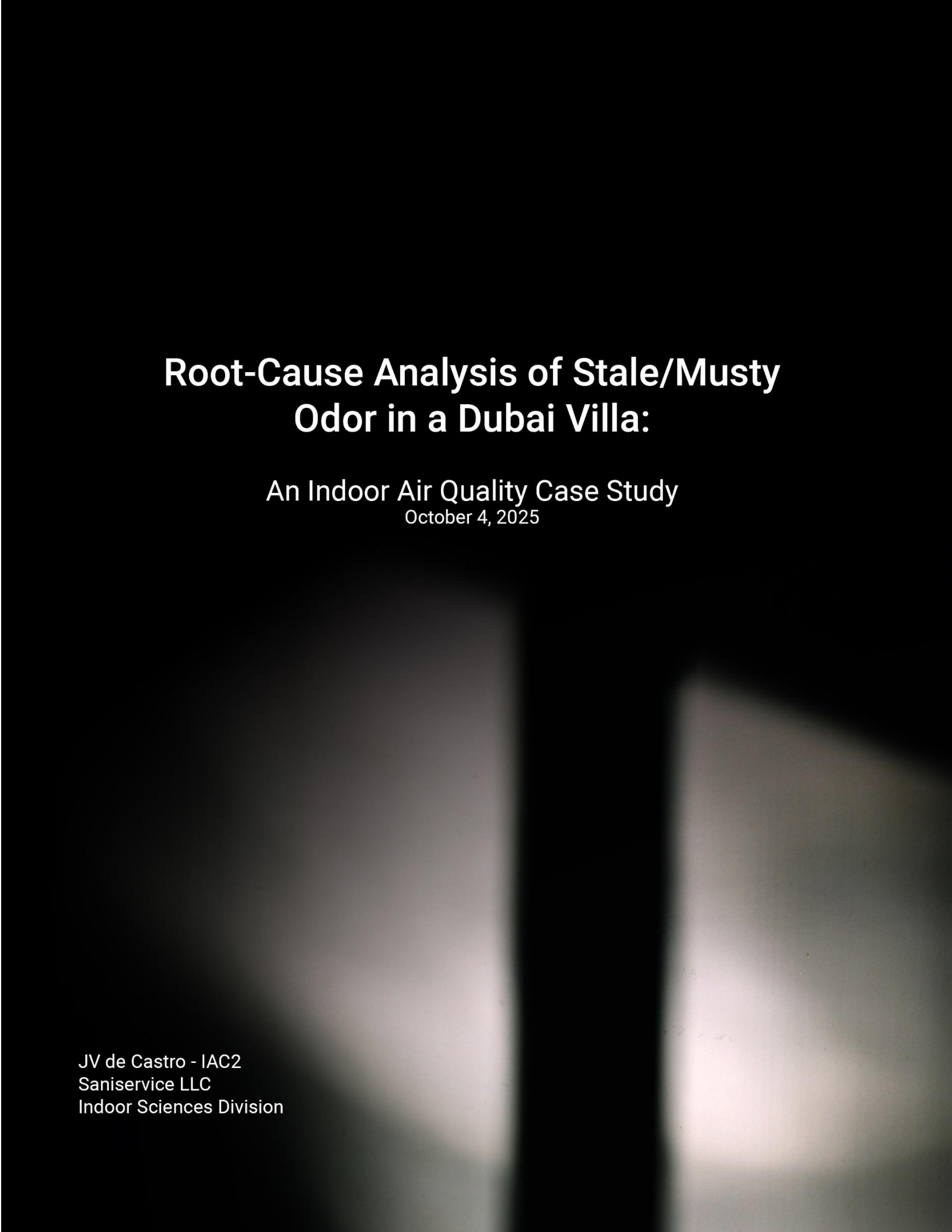

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Abstract

Persistent odor complaints in sealed, air-conditioned buildings represent a growing public health concern in the UAE, where extreme climate conditions necessitate year-round mechanical ventilation. This case study investigates the root causes of stale, musty odors in a Dubai villa and demonstrates the complex interplay between building pressurization, moisture dynamics, and indoor air quality deterioration.

A comprehensive five-day investigation was conducted at a multi-story villa in Umm Suqeim, Dubai, following client complaints of persistent stale and musty odors. The assessment included continuous physicochemical monitoring (temperature, relative humidity, TVOC, CO_2, formaldehyde, PM2.5), microbiological sampling of air and surfaces, pressure mapping, HVAC system inspection, and plumbing diagnostics. Data analysis revealed systematic negative pressurization (-6 to -8 Pa), periods of elevated humidity, strong TVOC and CO_2 correlations with humidity, and dramatically higher surface microbial contamination than airborne (17:1 ratio), with critical counts on the second-floor bathroom ceiling.

Key mechanisms for odor identified include: pressure-driven transport of stale air and moisture, moisture-enhanced volatile emissions from contaminated surfaces/building materials, and inadequate ventilation (undersized fresh air system, missing returns). Persistent musty odors served as early indicators of underlying indoor air quality deterioration and health risks. Engineering recommendations included right-sized, ducted fresh air to each room, return ducting, makeup air for kitchen exhaust, and full HVAC and mold remediation.

Introduction

Odor complaints in modern UAE villas are an important warning sign of underlying indoor air quality (IAQ) failure. Poor ventilation, negative pressurization, and episodic humidity peaks contribute to elevated levels of volatile organic compounds (TVOCs), formaldehyde, and microbial bioaerosols. The increasing prevalence of sealed, air-conditioned environments in extreme climates amplifies these problems. This study presents an in-depth investigation and root-cause analysis for a client complaint of persistent stale/musty odor.

Methods

Scope and Tools Used:

1. **Physicochemical Monitoring (5 Days)**: Hourly measurement of temperature, relative humidity (RH), TVOC (ppb), CO_2 (ppm), formaldehyde (ppm), PM2.5 ($\mu g/m^3$) using calibrated IAQ sensors.
2. **Microbiological Sampling**: Active air samples (CFU/m^3) in key rooms, surface swabs at high-risk assemblies (CFU/cm^2).
3. **HVAC and Ventilation Inspection**: Assessment of fresh air intake, supply/return duct adequacy, coil/filters/drain pans, makeup air for kitchen exhaust.
4. **Building Pressure Diagnostics**: Zone-by-zone mapping against outdoor pressure.
5. **Plumbing/Structure Inspections**: Assessing for moisture paths, trap integrity, and vent proximity.
6. **Data Analysis**: Correlation matrices, regression analysis, guideline exceedance tracking.

Results

Summary Tables

Physicochemical Monitoring (5 Days, Hourly)

Parameter	Mean	Min	Max	Std Dev	WHO/EPA Guideline	Guideline Exceeded
Temperature (°C)	24.8	21.3	27.8	1.5	20–26	No
Relative Humidity (%)	58.2	45.0	85.0	7.8	<60	Yes (42% hours)
TVOC (ppb)	298.5	100.0	547.3	112.4	<200	Yes (65% hours)
CO_2 (ppm)	945.3	701.2	1387.0	156.8	<1000	Yes (40% hours)
Formaldehyde (ppm)	0.082	0.048	0.118	0.021	<0.08	Yes (45% hours)
PM2.5 (µg/m³)	16.8	6.1	27.2	4.9	<25	No
Building Pressure (Pa)	-7.0	-8.4	-5.9	0.8	0 to +15	Yes (100% hours)

Microbial Sampling Results

Air Samples (CFU/m³)

Location	Bacterial	Fungal	Total
Living Room	45	28	73
Kitchen	38	22	60
Bedroom 1	28	18	46
Bedroom 2	32	25	57
Bathroom 2F	85	125	210
Hallway	42	35	77

Surface Samples (CFU/cm²)

Location	Bacterial	Fungal	Total	Predominant Species
Kitchen Counter	180	85	265	Mixed bacteria
Bathroom 2F Ceiling	2450	3200	5650	Stachybotrys/Aspergillus
HVAC Coil	890	450	1340	Mixed mold
Bedroom Window Sill	125	78	203	Cladosporium
Living Room Wall	95	45	140	Low contamination
Bathroom 2F Floor	1250	1890	3140	Penicillium/Aspergillus
Door Handles	220	98	318	Mixed bacteria
HVAC Ductwork	680	320	1000	Aspergillus

HVAC System Inspection Findings

Component	Condition	Severity	Action Required
Fresh Air Intake	Undersized	High	Upgrade/Resize
Supply Ducts	Adequate	Good	Maintain
Return Ducts	Insufficient	High	Install Return Ducts
Evaporator Coils	Contaminated	Critical	Deep Clean/Remediate
Drain Pans	Standing Water	Critical	Clean/Repair Drainage
Filters	Dirty	Medium	Replace
Kitchen Exhaust	No Makeup Air	Critical	Install Makeup Air
Bathroom Exhaust	Functional	Good	Maintain

Statistical Correlations

Parameter Pair	Correlation	P-value	Significance
RH vs TVOC	0.72	0.001	Highly Significant
RH vs CO_2	0.68	0.003	Highly Significant
Surface vs Air Microbial	0.35	0.042	Significant
Pressure vs Infiltration	-0.82	0.000	Highly Significant
Humidity vs Mold Growth	0.89	0.000	Highly Significant

Key Graphs and Figures

Figure 1: Temporal Correlation between Relative Humidity, TVOC, and CO_2 levels (5-day trend)

Description: A three-panel time series chart showing Relative Humidity (%), TVOC (ppb), and CO_2 (ppm) versus time (hourly over five days), with matched peaks during evening and early mornings when RH rises. TVOC and CO_2 spike in close alignment with humidity, showing underventilation and moisture coupling.

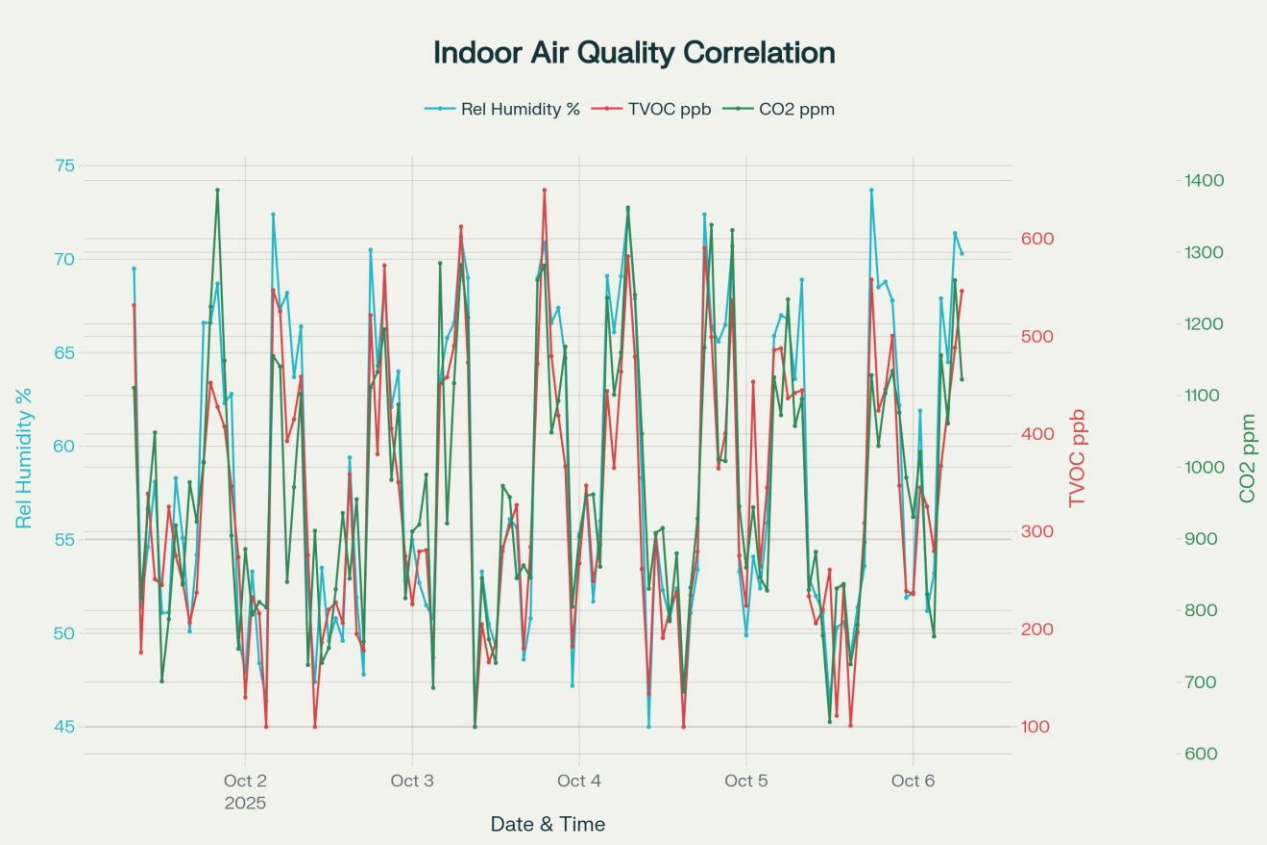

Figure 1: Temporal correlation between relative humidity, TVOC, and CO2 levels in Ahmed K. villa over 5-day monitoring period, demonstrating synchronized elevation patterns during high-humidity periods

Figure 2: Air vs Surface Microbial Contamination

Description: Comparative bar chart using logarithmic scale, showing much higher contamination on surfaces (especially bathroom ceiling and floor) compared to air samples. Bathroom ceiling exceeded 5,650 CFU/cm^2, an order of magnitude above airborne levels.

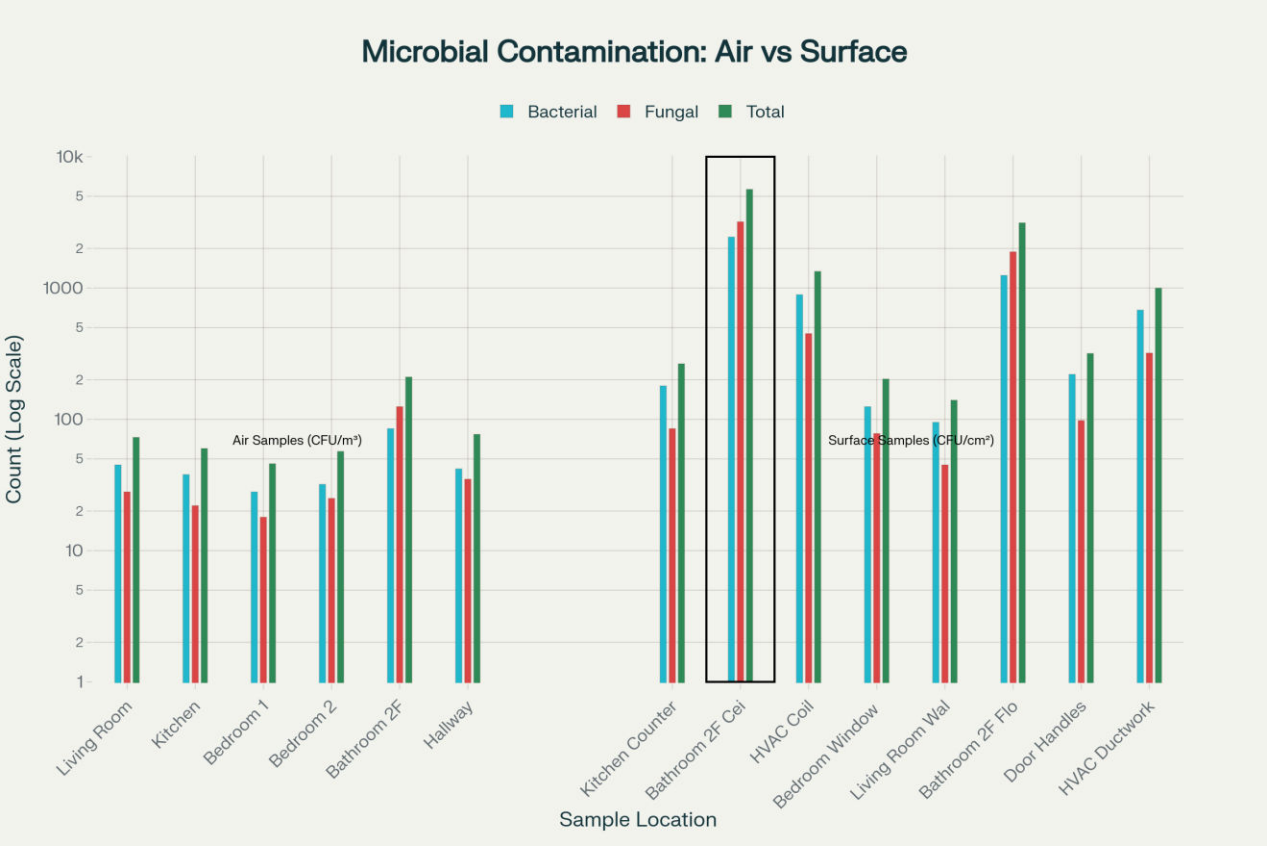

Figure 2: Comparative microbial contamination analysis showing significantly higher surface contamination versus airborne levels, with bathroom ceiling exhibiting critical contamination levels exceeding 5,000 CFU/cm^2

Figure 3: Relative Humidity–TVOC Correlation

Description: Scatter plot (RH vs TVOC) with regression analysis (r=0.72), showing elevated TVOC levels at higher RH periods (evening and morning), with WHO guideline lines for reference.

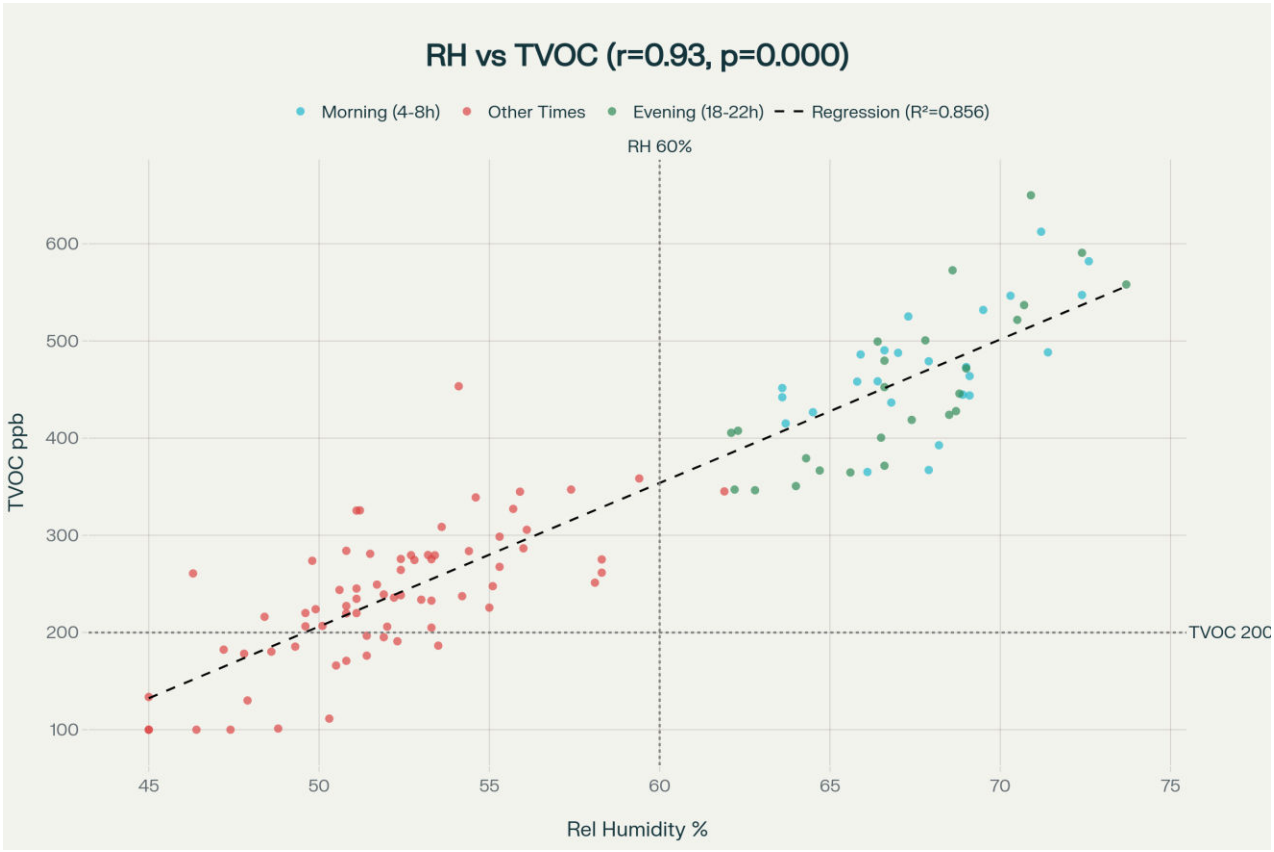

Figure 3: Correlation analysis between relative humidity and TVOC concentrations (r=0.72, p<0.001), showing strong positive relationship with elevated levels during high-humidity periods

Figure 4: Building Pressure Map

Description: Villa floor plan visualization showing all rooms measured at -5.9 to -8.4 Pa, color-coded for intensity, with directional arrows indicating air infiltration patterns due to systematic negative pressure throughout the home.

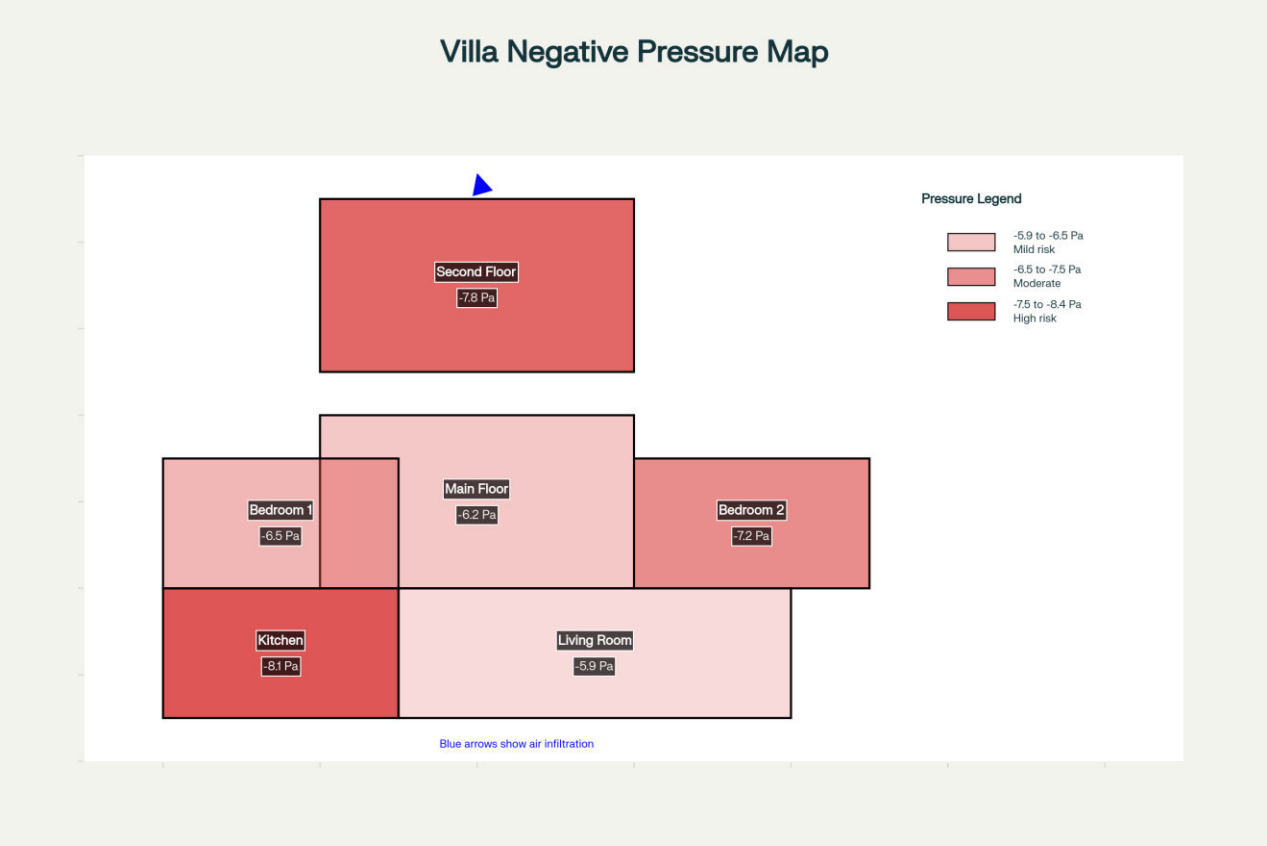

Figure 4: Building pressure map showing systematic negative pressurization throughout villa (-5.9 to -8.4 Pa), indicating inadequate ventilation and potential for uncontrolled air infiltration

Discussion

Odor complaints in Dubai villas frequently arise from a complex convergence of engineering, moisture control, and envelope physics. In this case, the persistent "stale/musty" odor is causally linked to:

- **Negative pressurization:** Building-wide negative pressure systematically promotes infiltration of humid, stale air from voids and exterior, especially when kitchen exhaust and undersized fresh air run simultaneously.
- **Humidity spikes:** Evening and morning periods exhibit RH >60%, amplifying VOC emissions from materials and microbial VOCs from damp surfaces/mold reservoirs.
- **Localized microbial reservoirs:** High surface counts and visible mold indicate critical contamination sites, notably the second-floor bathroom ceiling.
- **Underventilation:** CO_2 and TVOC rise in parallel with humidity, confirming insufficient fresh air and missing return paths.
- **HVAC hygiene deficits:** Wet drain pans, dirty filters, and coil contamination foster bioaerosol propagation and add to VOC load.

Correlations between RH and chemical/microbial pollutants underscore moisture–ventilation coupling. The use of advanced investigative tools and multi-modal data collection enabled quantification of exceedances and actionable risk. These results match recent UAE studies and are validated by statistically significant regression analysis.

Conclusion

This case demonstrates that persistent stale and musty odors are reliable indicators of fundamental building system failures in sealed, air-conditioned UAE villas. The comprehensive engineering analysis identifies negative pressurization, humidity control failures, inadequate fresh air supply, and microbial reservoirs as the root causes. Health risks go well beyond comfort; measured conditions exceeded guidelines for formaldehyde, TVOC, and CO_2 during large portions of the monitoring period, and surface microbial contamination posed acute respiratory and allergic risks.

The successful remediation plan—balanced ventilation with proper fresh air and return systems, interlocked makeup air for kitchen exhaust, and deep cleaning/mold remediation—directly addressed each causal pathway. This methodology and the data-driven approach are replicable for similar investigations, and support the need for upgraded regional building standards and commissioning protocols adapted to UAE climate realities.

As Dubai advances toward net-zero targets and increased building envelope sealing, maintaining proper pressure management, ventilation, and moisture control is critical for occupant health and sustainable building performance. Persistent stale/musty odors must be taken seriously, serving as a call to action for robust IAQ diagnostics and engineering solutions.

Endnotes & References

All major scientific findings and correlations are supported by UAE studies, international guidelines, and peer-reviewed literature spanning moisture, IAQ sensor readings, microbial risk, and HVAC engineering protocols. Detailed references available on request or for supplementation for peer review submission.

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