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We will begin at: 11:00 AM EDT

Emerging Threats to Indoor Air Quality (IAQ) and Human Health

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Webinar Series 2024-2025
“Emerging Threats to Indoor Air Quality (IAQ) and Human Health”
Presented by Chemical Insights Research Institute of UL Research Institutes

Moderators:
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According to the United States Environmental Protection Agency (EPA), most Americans spend 90% of their time indoors. Although outdoor air pollution is thought to be a primary public health concern, short- and long-term exposure to indoor air pollutants may have profound effects on human health and wellbeing. Recent studies have shown indoor air contaminants consisting of biological or chemical pollutants can lead to a variety of health conditions including increased susceptibility to infections, chronic respiratory conditions such as asthma, and lung cancer. Within this webinar, Chemical Insights Research Institute of UL Research Institutes will highlight threats to indoor air quality that stem from the use of various consumer products such as emissions from 3D printers and electronic nicotine delivery systems (ENDS) or e-cigarettes. Additionally, we will describe how extreme heat events propagated by climate change may also jeopardize indoor air quality.
Learning Objectives

1. Discuss parameters that influence indoor air quality such as ventilation, humidity, and temperature

2. Identify chemical and particle emission profiles that are generated while operating 3D printers, during ENDS usage, and from building materials during extreme heat events

3. Discover potential human health implications that might arise due to indoor air pollutant exposure
Agenda

About Chemical Insights Research Institute (CIRI)

Emerging Threats to IAQ

Impacts on IAQ – Case Studies from CIRI Research

What Can We Do?

Discussion and Q/A
About Chemical Insights Research Institute (CIRI)
Chemical Insights
Research Institute
About CIRI

Chemical Insights Research Institute is dedicated to scientific research, publication, education, and communication on environmental exposures resulting from technologies, and practices, their impact on human health and ways for reducing risks.

Our research efforts contribute to safe working, living, and learning environments for the betterment of societal well-being.
CIRI Research Initiatives

- 3D Printing Emissions
- E-Cigarettes & Vaping
- Furniture Flammability
- Global Air Pollution
- PFAS Exposure
- Building Resilience
- Toxicology
- Wildfire Emissions
Exposure Chamber Technology

A stainless steel exposure chamber with realistic air flow, temperature and humidity.

INPUTS: Emerging technologies or products with suspected health hazards

Specialized filtration removes all particles and chemicals from outside air supplied to the chamber to ensure a clean environment.

OUTPUTS: Actionable Data, Safer Use & Application

Interface with specialty equipment allows for the collection of data, complex analysis and human exposure modeling.
New Approaches to Assessing Health Impacts

Characterize and Assess “Real World” Exposure Scenarios

- Determine chemicals or particles of interest in emissions/aerosols
- Develop chemical library for use in high-throughput tox screening

In Vitro Mechanic Assessment

- Identify pathways of cellular damage, alteration, and disease
- Characterize biomarkers of exposure and injury

Hypothesis-Based Molecular Epidemiology Studies

- Establish causality between biomarkers of exposure and injury
- Create library of biomarkers associated with increased disease risk
Emerging Threats to IAQ
Where Do Pollutants Come From Indoors?

- Vehicles
- Flooring
- Upholstery
- Surfaces
- Furniture
- Paint
- Bedding
- Insulation
- Cleaning
- Printing
- Supplies
- Moisture
- Pets
- People
Sources of Pollutants
What Pollutants Come from These Sources?

- Volatile organic compounds (VOCs)
- Semi-volatile organic compounds (SVOCs)
- Particles (coarse and fine)
- Molds, allergens and biological pollutants
- Carbon monoxide
- Ozone

Source: Reference Guide for Indoor Air Quality in Schools: Typical Sources of Indoor Air Pollutants
U.S. Environmental Protection Association
KNOWN HEALTH IMPACTS

- Irritation of the eyes, nose, and throat
- Headaches, dizziness, and fatigue
- Respiratory diseases (e.g. asthma, COVID-19)
- Heart disease
- Cancer
Sensitive Populations
Health Consequences: Children

All children are considered sensitive to air pollution.

Children:
• Engage in more vigorous activity
• Inhale more air per pound of body weight
• Have developing organs and immature immune response
Health Consequences: Disadvantaged Populations

- Structural racism
- Disproportionate health burdens from environmental conditions
- Existing health disparities (e.g., higher burden of asthma and cardiovascular disease)
- Less access to resources (e.g., quality health care)
- Barriers to receiving language- and culturally appropriate care

Source: Which Populations Experience Greater Risks of Adverse Health Effects Resulting from Wildfire Smoke Exposure? U.S. Environmental Protection Association
EMERGING RISKS CONTRIBUTING TO POOR IAQ

3D printers (New/emerging technologies)

Emissions generated by ENDS (Vaping)

Increased pollutant exposure from climate & weather

Cleaning to mitigate aerosol transmission
Emerging Risk: 3D Printers
During operation, 3D printers generate a complex mixture of airborne particles and volatile organic compounds (VOCs).
...which means exposure may present a human health hazard, in particular when a person stands next to the printer with minimal ventilation.
Emerging Risk: Vaping
Emerging Risk:
Increased Pollutant Exposure from Climate & Weather
Stressors: External and Internal

- High Winds
- Storms
- Fire
- Chemicals
- Mold
- Particles
- Extreme Heat
- Snow
- Flood
- Temperature
- Humidity
- Dust & Allergens
THE EFFECT OF TEMPERATURE AND MOISTURE ON A BUILDING’S INTERIOR

MOLD GROWTH
Stachybotrys chartarum (greenish-black mold)
Can grow on material with a high cellulose content (fiberboard, gyp board)

CHEMICAL OFF-GASSING
When temperature and humidity levels rise, the ability of certain chemicals to “migrate” from a material into the air and settled dust
Emerging Risk: Changes in cleaning practices to mitigate aerosol transmission
More is NOT Better!
Diluting contaminants (through ventilation) works BETTER than killing contaminants (through disinfection).
Impacts on IAQ – Case Studies from CIRI Research
Case Study 1

Examining the Role of Vaping Behavior on Secondhand Chemical Exposure and Inhalation Risks
ELECTRONIC NICOTINE DELIVERY SYSTEM (ENDS)

Tanks or Mods
- 3rd Generation
- Rechargeable
- Reusable
- Highly modifiable
  • = “Mod

Pod Mods
- 4th Generation
- Rechargeable
- Prefilled/refillable “Pod”
- Modifiable “Mod”
- Nicotine salt
  • Lower pH
  • Allow high levels of nicotine to be inhaled with less irritation

Disposable Mods
- 4th Generation
- Non-reusable
- Non-refillable
- Most recent models provides the feature to recharge the device but not the e-liquid

E-liquids
- Menthol
- Cotton candy
- Sour Candy
- Golden Tobacco
- White Gummy
- Kiwi Strawberry
- Iced Mango Berry
- Passion Fruit Guava
- Energy Drink Skittles
- Nicotine: 3-5%
Human Subjects and Study Design

Secondhand Vaping Assessments

- Recruitment:
  - Healthy adults, ages 18-35 years.
  - No dual tobacco use or use of other nicotine.

- Puffing Topography Assessment:
  - Puff volume, flow rate, inter-puff interval, puff duration.

- Particle Monitoring:
  - Scanning Mobility Particle Sizer, Optical Particle Sizer, VOC and aldehyde monitoring.

- Oral Health Exam and Biosample Collection:
  - Collection of saliva, gingival epithelial swabs and plaque samples for analysis.

Firsthand Vaping Assessments

Applied puffing topography assessment parameters to an ENDS Aerosol Generating System and primary emissions were characterized.
PUFFING TOPOGRAPHY: Establishing Behavior Based Exposure Mediators

PCA reveals:
- Puff Volume
- Flow rate
- Highest correlation and contributed significantly to the explained total variance.

Groupings were not dependent upon:
- Participant sex
- Brand or nicotine level used
- Exhaled forced vital capacity
THE RELATIONSHIP BETWEEN EXPOSURE MEDIATORS:
Particle Emissions

A. Total Particle Count

- Puff volume and flow rate mediate total particle counts:
- Higher the puff volume and flow rate, the more particles are generated by device and user.

B. Total Particle Mass

- Puff volume and flow rate mediate total particle mass:
- Higher the puff volume and flow rate, more particle mass is emitted by the device and user.

C. Geometric Mean Diameter

- Puff volume and flow rate mediate impact emitted particle diameter
- Emitted particles are all within same nano-range.
THE RELATIONSHIP BETWEEN EXPOSURE MEDIATORS: Metal Emissions

Vanadium

- Low
- Medium
- High

Nickel

- Low
- Medium
- High

Zinc

- Low
- Medium
- High

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PUFF VOLUME BASED VOCS EMISSION:
Comparison of Firsthand and Secondhand Vaping Exposures

Firsthand and secondhand emissions shared more than 50% of the total detected VOCs

Firsthand VOC Emissions

Secondhand VOC Emissions

Top Ten Shared VOCs
RESPIRATORY HEALTH IMPLICATIONS: Biomarkers of Exposure and Lung Injury

Oxidative Stress and DNA Damage
Conclusions and Future Directions

1) Puffing topography analysis revealed potent exposure mediators including puff volume and flow rate.

2) Increasing levels of particles and VOCs in firsthand (device) and secondhand emissions (user) were observed due to increasing puff volumes.

3) Significant increase in pro-inflammatory cytokines, which can cause lung inflammation and reduced epithelial barrier integrity leading to reduced lung function.

Develop Consumer Guidance Document

- Highlight how unique consumer vaping patterns and preferences can enhance exposure to:
  - Particulates
  - Metals
  - VOCs
- Illustrate inhalation and oral health risks:
  - ENDS users
  - Family members, friends, or bystanders
Case Study 2

Metabolic and Toxicological Effects of 3D Printer Particulate Emissions Found within High Schools
Exploring 3D Printer Emissions in HS Classrooms

- Three-dimensional (3D) printer usage across educational settings has increased.
- Health concerns have emerged due to chemical and particle emission exposures during standard operation.
- However, little is known about the impact of 3D printer emission exposures on respiratory health.
Fused Filament Material Extrusion Process

- **Filament**: Fed from a spool to the extruder.
- **Motor**: Controls and feeds the filament.
- **Heater**: Melts the filament.
- **Print nozzle**: Extrudes the melted filament to form a 3D object.
- **Print bed**: Holds deposited layers of melted filament.
Particle Emission

- Particle emissions from 3D printers could reach up to 1,000,000,000,000 \(10^{12}\) particles per hour

- Particle exposure may cause health problems, including:
  - Eye, nose and throat irritation
  - Aggravation of coronary and respiratory disease symptoms
  - Premature death in people with heart or lung disease

- Most are ultrafine particles (UFPs) smaller than 100 nanometers in size, which present a major health concern
Field Study Methods

3D Printer Operation
- Monitor and Sample Particulate Emissions

Expose Small Airway Cells

Toxicological Analysis
- In Silico Analysis

3-hr operation with ABS or PLA filaments
- Scanning Mobility Particle Sizer (10-420 nm)
- Optical Particle Sizer (0.3-10 μm)

Extract PM and expose cells to 5 and 10 μg/mL

MTS viability assay
- DNA damage
- Cytokine release
- HPLC-MS metabolomic profiling

Pathway enrichment analysis
3D Printer Emission Profiles

![Graph showing emission profiles for different 3D printing materials. The graph plots dN/dlogDp (#/cm^3) against Dp (nm). The profiles are labeled as follows:
- CTRL (2053#/cm^3)
- BG (1578#/cm^3)
- ABS_PRINT (4559#/cm^3)
- PLA_PRINT (1849#/cm^3)
]
3D Printer Emission Impact on SAEC

A. Cell Viability

B. MDM2

C. IL-1b

D. MMP-9

E. Rantes

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Conclusions

- ABS and PLA filament emissions have distinct aerosol properties that led to differences in the estimated inhaled and in vitro deposited doses.
- Differences in dose led to corresponding filament specific differences in cell viability and inflammatory responses.
- While both ABS and PLA emissions significantly increased MDM2, PLA emissions exposures additionally increased gamma H2AX.
Case Study 3

The effect of moderate temperature rise on emitted chemicals from modern building materials
Background

The Global (Chemical) Landscape

- Chemical pollutants are preeminent and numerous
- 40-fold increase during the last 150 years

“Chemical intensification”
- Industry → daily use
- Legacy and emerging
  - Pesticides, PAHs, heavy metals, VOCs, PFAS & microplastics
Indoor air quality

- Internal chemical landscape
  - Indoor air quality poorer than outdoors

- Can building materials behave differently based on these stressors?
  - There are links between temperature, humidity, and chemical emissions.
  - One example: formaldehyde (CH$_2$O)
    - FEMA trailers, Hurricane Katrina (temperature and humidity)
The investigation

• Lack of literature on building materials themselves – just indoor environment as a whole and only certain materials
• Introduce deliberate design questions and choices and real-world environmental conditions

Big picture questions:
1. What are the effects of moderate temperature rise on building material chemical profiles?
2. Can the current testing and certification standards adequately address these adverse climate events now and in the future?
Study Design and Methods

Materials Selection
→ Representative indoor materials were studied

Microchamber Assessments
→ Four sampling chambers with individual sampling port
→ Two temperature setpoints:
  • Room temp: 23°C
  • Elevated temp: 35°C

Sampling Conditions
→ Constant flow (0.2 L/min) to sampling tubes
→ Tenax TA for VOCs – 15 minutes
→ DNPH for ALDs – 30 minutes

VOC/ALD Characterization
→ TD-GC/MS
→ HPLC
Material Sample Details
Increase in TVOC and TALD (In Elevated Conditions)

<table>
<thead>
<tr>
<th>TVOCs</th>
<th>% Increase</th>
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<tr>
<td>MDF</td>
<td>-12%</td>
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<tr>
<td>Insulation</td>
<td>30%</td>
</tr>
<tr>
<td>Drywall</td>
<td>54%</td>
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<tr>
<td>Natural Wood Flooring</td>
<td>89%</td>
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<tr>
<td>Engineered Wood Flooring</td>
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<tr>
<td>Laminate Flooring</td>
<td>334%</td>
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<tr>
<td>Vinyl Flooring (1)</td>
<td>241%</td>
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<tr>
<td>Vinyl Flooring (2)</td>
<td>37%</td>
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<tr>
<td>Carpet Flooring</td>
<td>5%</td>
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<tr>
<td>Crown Molding</td>
<td>291%</td>
</tr>
<tr>
<td>Baseboard</td>
<td>103%</td>
</tr>
<tr>
<td>Paneling, oil-finish</td>
<td>181%</td>
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<tr>
<td>Paneling, water-finish</td>
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<tr>
<td>Wallpaper Covering</td>
<td>190%</td>
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<tr>
<td>Acoustic Tile</td>
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<table>
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<tr>
<th>TALDs</th>
<th>% Increase</th>
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<td>Vinyl Flooring (1)</td>
<td>67%</td>
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<td>Carpet Flooring</td>
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<tr>
<td>Crown Molding</td>
<td>186%</td>
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<tr>
<td>Baseboard</td>
<td>114%</td>
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<tr>
<td>Paneling, oil-finish</td>
<td>-78%</td>
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<td>Paneling, water-finish</td>
<td>23%</td>
</tr>
<tr>
<td>Wallpaper Covering</td>
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</tr>
<tr>
<td>Acoustic Tile</td>
<td>-</td>
</tr>
</tbody>
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This demonstrates that current certifications that use TVOC limits may not be applicable in expanding real word scenarios.
Frequently Detected Chemicals (Across Material Types)

**Building Materials**
- Acoustic tile
- Baseboard
- Carpet flooring
- Crown molding
- Drywall
- Insulation
- Laminate flooring
- MDF
- Natural wood flooring
- Paneling, oil-finish
- Paneling, water-finish
- Vinyl flooring
- Wallpaper covering
- Wood flooring

**Frequently Detected Chemicals**

**Irritants**
- Octanal
- Hexadecane (Cetane)
- Dodecane
- Acetonitrile

**Renal Toxicants**
- Hexanal
- Decanal

**PFAS-like**
- 1,1-Dichloro-1-fluoroethane
New Chemicals of Concern (from vinyl flooring at elevated temperature)

Benzophenone
- IARC Group 2B carcinogen
- Possible human carcinogen
- Endocrine disrupting chemical
- Estrogenic activity
- Neurotransmitter inhibitor
  - Acetylcholinesterase inhibitor

Neodecanoic acid
- Toxic pneumonitis
  - Chemically induced pulmonary inflammation
- Dermal/ocular irritant
  - Contact dermatitis and ocular edema
Conclusions

1. Many materials indicated increased emission rates of VOCs at 35°C

2. Materials with higher surface area in the built environment are of the most concern and deserving of greater scrutiny, especially in vulnerable populations

3. An accurate picture of chemical load in the indoor environment is still needed based on the climate events predicted in the near future.
What Can We Do?
Strategies for Healthy Indoor Air Quality in Schools

- Source Control
- Cleaning Effectiveness
- Ventilation & Filtration
- Moisture & Temperature Control
- Occupant Education
One of the most effective ways to minimize exposure to indoor air pollutants is to prevent emissions in the first place.
Source Control Strategies

Specify/buy certified or verified low-emission and specific chemical-free products.

Air products out before use.

Require all vendors/suppliers to use verified low-emission/specific chemical-free products.

Use products as recommended. Dispose of products safely.
Cleaning Effectiveness

Practice good source control. Only use disinfecting products approved by the US EPA.

Vacuum floors, textiles, and furniture with a HEPA vacuum. Remove dust from all flat surfaces (not just floors).

Focus cleaning on high touch surfaces. Use cleansers in well-ventilated spaces and open windows.

Implement routine cleaning programs to avoid build-up of settled dust and films.
Ventilation and Filtration

- A properly working HVAC system dilutes pollutants and transports them outside. Incorporate at least 15-20% outdoor air at all times.

- Filter fresh air with the highest MERV filter possible. Consider building-specific requirements (i.e., HEPA filtration in healthcare).

- Check ductwork for leaks to reduce contaminants in the plenum space. Return air should never be expelled into an open plenum.

- Maintain operational strategies that keep the system running at least 2 hours before & after occupancy. Plan ongoing maintenance (i.e., changing filters).
Supplemental Air Cleaning

Integrate air cleaning technologies directly into the HVAC system to clean the conditioned air that will be circulated throughout the building.

Use of stand-alone air cleaners to supplement the HVAC system in high volume areas or areas with potential pollutants.
Moisture & Temperature Control

Maintain indoor humidity levels between 40 and 60%.

Maintain temperature range based on ASHRAE 55 (67-82 °F)

Use dehumidifiers.

Repair all chronic water leaks or entry points to prevent water intrusion and damage.

Dry wet materials quickly. Remove chronically wet materials.
Independent, Third-Party Resources

Source Control:
- GreenScreen® For Safer Chemicals
- UL GREENGUARD Certification Program
- EPA Greener Products and Services

Cleaning Effectiveness:
- EPA-Registered Disinfectants
- Green Seal
- The CIMS Standard (ISSA)

Ventilation and Filtration:
- EPA Clean Air in Buildings Challenge

Stand Alone Air Cleaners:
- Harvard Portable Air Cleaners
- NIH Selection and Use of Portable Air Cleaners

Facility Management
- GSA Sustainable Facilities Tool
- OSHA Building Operations and Management
- Whole Building Design Guide: Sustainable O&M Practices
Discussion and Q/A
Thank You

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