

ENVIRONMENTAL RELATIVE MOLDINESS INDEX (ERMI)

ORIGINS, METHODOLOGY, INTERPRETATION, APPLICATIONS, AND LIMITATIONS

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Background and Summary

The Environmental Relative Moldiness Index (ERMI) is a DNA-based analytical tool developed by researchers at the U.S. Environmental Protection Agency (EPA) in collaboration with the U.S. Department of Housing and Urban Development (HUD). The index was designed to provide a standardized, quantitative measure of indoor mold contamination in residential settings, with particular emphasis on identifying mold populations associated with water damage (Vesper, et al., 2007; Vesper, et al., 2021; Vesper S. , The Development and Application of the Environmental Relative Moldiness Index (ERMI), 2025).

The ERMI is derived from mold-specific quantitative polymerase chain reaction (MS-qPCR) analysis of 36 fungal species detected in settled household dust. Twenty-six of these species (Group 1) are associated with water-damaged indoor environments, while ten (Group 2) are common outdoor molds found in homes independent of water damage. The ERMI score – a unitless number typically ranging from approximately -10 to +20 – is calculated by subtracting the sum of the logarithmic concentrations of Group 2 molds from the sum of the logarithmic concentrations of Group 1 molds (Vesper, et al., 2007; Vesper, et al., 2021; Vesper S. , The Development and Application of the Environmental Relative Moldiness Index (ERMI), 2025).

The ERMI scale was anchored to a national reference population of 1,096 U.S. homes sampled during HUD's first American Healthy Homes Survey (AHHS I). This database places any individual home's score in percentile context relative to the national housing stock (Vesper, et al., 2007).

The American Healthy Homes Survey (AHHS I)

The foundational dataset for the ERMI was assembled through HUD's first American Healthy Homes Survey (AHHS I), conducted in 2005-2006. Investigators collected standardized dust samples from 1,096 homes selected to represent the continental U.S. housing stock – the first statistically representative national survey of indoor mold populations (Vesper, et al., 2007).

Each participating home provided a single composite dust sample collected by vacuum from specified areas of the bedroom and living room carpet. These samples were subjected to quantitative PCR analysis for 82 indoor mold species. Of those, 36 species met the criterion of a national distribution, defined as a geometric mean concentration of at least one spore equivalent per mil-

EPA Species Group 1 (s1)

Aspergillus flavus
Aspergillus fumigatus
Aspergillus niger
Aspergillus ochraceus
Aspergillus penicillioides
Aspergillus restrictrus
Aspergillus schlerotiorum
Aspergillus sydowii
Aspergillus unguis
Aspergillus versicolor
Eurotium (A.) amstelodami
Aureobasidium pullulans
Chaetomium globosum
Cladosporium spaerospermum
Paecilomyces variotii
Penicillium brevicompactum
Penicillium corylophilum
Penicillium crustosum (group2)
Penicillium purpurogenum
Penicillium spinulosum
Penicillium variabile
Scopulariopsis brevicaulis
Scopulariopsis chartarum
Stachybotrys chartarum
Trichoderma viride
Wallemia sebi

EPA Species Group 2 (s2)

Acremonium strictum
Alternaria alternata
Aspergillus ustus
Cladosporium cladosporioides I
Cladosporium cladosporioides II
Cladosporium herbarum
Epicoccum nigrum
Mucor and Rhizopus group
Penicillium chrysogenum
Rhizopus Stolonifer

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ligram of dust across all 1,096 homes (Vesper, et al., 2007).

The 36 nationally distributed molds were then classified into two categories based on their epidemiological associations. Five were immediately recognizable as water-damage indicator molds (Stachybotrys chartarum, Aspergillus versicolor, A. fumigatus, Trichoderma viride, and Chaetomium globosum), and five were well-known outdoor molds. The remaining 26 were assigned to Group 1 or Group 2 based on their differential concentrations in water-damaged versus non-damaged homes. ERMI values for all 1,096 homes were then assembled from lowest to highest to produce the ERMI scale (Vesper, et al., 2007).

A second survey, AHHS II, completed in 2019 with 695 homes, subsequently confirmed that ERMI values in U.S. homes had remained relatively stable over the intervening decade, validating the national reference database for ongoing comparative use (Vesper, et al., 2021).

Analytical Methodology

Mold-Specific Quantitative Polymerase Chain Reaction (MS-qPCR)

The analytical backbone of the ERMI is MS-qPCR – a DNA-based quantification technology that detects and measures the concentration of specific mold species by targeting unique genomic sequences. Unlike conventional culture methods that require viable spores and weeks of incubation, or microscopic spore-trap methods that cannot distinguish morphologically similar species, MS-qPCR offers several significant advantages:

- Detection of both viable and non-viable fungal material (spores, hyphal fragments, dead cells)
- Species-level resolution for morphologically ambiguous genera (Aspergillus, Penicillium)
- Quantitative results in cell equivalents per milligram of dust (CE/mg dust)
- High sensitivity, capable of detecting species present at very low concentrations
- Reproducibility across replicate samples from the same home

The MS-qPCR process involves extracting DNA from a standardized 5.0 mg aliquot of sieved settled dust, amplifying mold-specific target sequences using fluorescently labeled primers and probes (TaqMan chemistry) and quantifying the amplification signal in real-time. The laboratory uses PCR to make millions of copies of DNA segments that are unique to each mold species being tested (a process known as "TaqMan chemistry"). As those copies are being made, specially designed chemical tags attached to the DNA give off a flash of light each time a new copy is produced. A laboratory instrument measures that light in real time as the copying proceeds. The more mold of a particular species that was present in the original dust sample, the faster and brighter the light signal appears. By comparing that signal to a reference chart built from known quantities of the same mold DNA, the laboratory calculates how much of each mold species was in the dust. The result for each species is expressed as cell equivalents per milligram of dust (CE/mg dust), derived by comparison to a known standard curve.

Dust Sample Collection Protocol

The standard ERMI protocol specifies collection of settled dust from carpet in two rooms – typically the master bedroom and living room – using a specialized vacuum sampling device fitted with a fine-mesh filter cassette. The combined sample represents a composite of mold deposition over days to months, providing a time-integrated



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picture of the indoor mold burden rather than a real-time snapshot (Vesper, et al., 2007; Vesper, et al., 2021).

For non-carpeted homes, alternative collection methods have been evaluated, including electrostatic wipes (Swiffer-type cloths) and vacuum collection from hard floor surfaces. While these methods have shown acceptable correlation with the standard carpet vacuum method, the national reference database (AHHS) was established exclusively using carpet vacuum samples, introducing a potential comparability issue when alternative methods are used. In cases where a home is empty and thoroughly cleaned, an electrostatic collection cloth can be used to collect dust from above floor surfaces like the top of doors or door molding, ceiling lamps, venetian blinds, etc. These samples have been found to provide comparable ERMI results to the standard dust sample. Therefore, the ERMI metric is applicable to the many forms of settled-dust collection (Cox, et al., 2017; Vesper S. , The Development and Application of the Environmental Relative Moldiness Index (ERMI), 2025).

Key collection parameters from the original EPA protocol include:

- The designated sampling area should be approximately two square meters per room.
- Sample the substrate. Carpet (short-pile with fibers that stand between one-quarter to one-half inch tall) in low-low-traffic areas are preferred.
- When it is necessary to collect dust from a non-porous floor, vacuum the dust at a rate of approximately one square meter per minute.
- The sample should be collected using a cartridge with an inner dust collector that fits onto the wand of a vacuum cleaner. The use of a HEPA vacuum is preferred.
- Conduct composite sampling (i.e., a single combined sample submitted from both rooms).
- The laboratory aliquot should be 5.0 mg of sieved dust analyzed per run.

MS-qPCR analysis can also be applied to 48-hour air samples (using an inhalable sampler) to calculate an ERMI-like value. Studies have shown that ERMI-like values correlate well with dust samples and are highly useful in situations where dust sampling is impossible, such as newly gutted or recently sanitized homes (Cox, et al., 2017; Vesper, Libuit, Esguerra, & Cross, 2022).

It is noteworthy that several Group 1 species – particularly Stachybotrys chartarum, Chaetomium globosum, and Aspergillus versicolor – are recognized mycotoxin producers and are strongly associated with sustained water intrusion (requiring water activity ≥ 0.90 and sustained moisture over days to weeks). Their presence in settled dust, even at low concentrations, may carry significant clinical and forensic weight independent of the aggregate ERMI score.

ERMI Score Calculation

In mycology, fungal populations grow exponentially; therefore, a linear scale is insufficient for measuring concentrations. Therefore, a logarithmic scale is utilized to manage the vast range of cell counts found in the field. The mathematical formula for the index is:

$$\text{ERMI} = \sum \log_{10}(\text{Group 1 Molds}) - \sum \log_{10}(\text{Group 2 Molds})$$

Summing the logs normalizes the data, providing a relative value of indoor moldiness. This methodology's stability was validated by the American Healthy Homes Survey (AHHS). AHHS I (2004, n=1,096) established the national baseline, and AHHS II (2019, n=695) confirmed significant concordance ($p<0.001$) in mold detection rates and geometric means. Interestingly, AHHS II revealed higher average ERMI values, largely because older homes (Pre-1978) were more heavily represented and exhibited higher Group 1 populations due to infrastructure aging (Vesper, et al., 2007; Vesper, et al., 2021).

For each species, the concentration is log-transformed (base 10) before summation. If a species is not detected, a value of 0 (log□□ of 1 CE/mg) is used, as the log of zero is undefined. The resulting ERMI score is a unitless number reflecting the relative dominance of water-damage-associated mold species over background outdoor mold species within the home's settled dust.

Interpreting ERMI Results

The National ERMI Scale and Quartiles

The ERMI scale spans approximately -10 to +20, with the distribution of values anchored to the AHHS I national reference population. Because values are assembled from lowest to highest, the ERMI score conveys where a given home falls in the national distribution of mold burden. The scale is divided into four quartiles:

ERMI Score Range	Quartile	Interpretation	National Percentile
-10 to -4	Q1 (Lowest)	Low relative moldiness; mold contamination unlikely	0-25th percentile
-4 to 0	Q2	Moderately low; generally acceptable mold burden	25th-50th percentile
0 to +5	Q3	Moderately high; elevated mold burden; investigation warranted	50th-75th percentile
+5 to +20 (or higher)	Q4 (Highest)	High relative moldiness; substantial water-damage mold burden; further investigation needed	75th-100th percentile

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It is essential to note that the quartile thresholds reflect the distribution of mold contamination in U.S. homes – not health thresholds. A Q4 score does not automatically indicate a health hazard; it indicates that the home has a higher mold burden than approximately 75% of U.S. homes sampled. Conversely, a Q1 score does not guarantee the absence of health-relevant mold species, particularly if a potent mycotoxin-producing species is present at low concentration.

Species-Level Interpretation

The aggregate ERMI score should not be the sole or primary basis for interpretation. The individual species results carry equal or greater forensic and clinical significance. Key considerations include:

1. Water-Damage Indicators: Stachybotrys chartarum and Chaetomium globosum require sustained, heavy moisture (>0.90 water activity) to colonize and sporulate. Detection of either species in settled dust – even at low concentrations – is an indicator of past or present significant water intrusion. Stachybotrys, in particular, does not readily shed spores under dry conditions, meaning its presence in settled dust is suggestive of serious and prolonged moisture damage. See Table 1 (page 5).

2. Aspergillus penicillioides and Wallemia sebi: These two xerophilic species (capable of growth at relatively low water activity, as low as 0.70-0.75 aw) may indicate a different type of moisture problem – persistent low-level humidity or condensation rather than acute flooding or intrusion. Their inclusion in the ERMI Group 1 and their prominence in the HERTSMI-2 subset reflects their association with occupant health outcomes in certain epidemiological studies. See Table 1 (page 5).

3. The HERTSMI-2 Subset: The Health Effects Roster of Type-Specific Formers of Mycotoxins and Inflammagens, 2nd Version (HERTSMI-2) is a five-species derivative tool developed by Dr. Ritchie Shoemaker, MD, from ERMI data. It focuses on the five species most closely associated with Chronic Inflammatory Response Syndrome (CIRS) in Shoemaker's clinical protocols – Aspergillus penicillioides, Aspergillus versicolor, Chaetomium globosum, Stachybotrys chartarum, and Wallemia sebi. The HERTSMI-2 score uses a weighted point system (0, 4, 6, or 10 points per species based on concentration thresholds) with total scores below 11 suggesting relative safety for CIRS patients, 11-15 borderline, and above 15 indicating an unsafe environment. Shoemaker explicitly describes the 11-15 range as "unreliable for prediction" and "indeterminate," necessitating further building evaluation and remediation before patients re-enter. The HERTSMI-2 was designed for and should be interpreted within the context of Dr. Shoemaker's specific clinical protocols (Shoemaker & Lark, 2016).

Comparison to Visual and Olfactory Inspection

A 2009 study by Vesper et al. comparing ERMI values to walk-through inspections and occupant questionnaires from the AHHS found that homes in the highest ERMI quartile were in agreement with visual inspection and/or occupant-reported mold or moisture only 48% of the time. This means that 52% of Q4 homes had no detectable visual mold or moisture odor – and conversely, some lower-ERMI homes had visible mold (Vesper, McKinstry, Cox, & Dewalt, 2009; Vesper S. , The Development and Application of the Environmental Relative Moldiness Index (ERMI), 2025). This divergence reflects several realities:

- Mold can be hidden within wall cavities, beneath flooring, or in HVAC systems where visual inspection is not revealing
- DNA-based analysis detects non-viable fungal material that may have accumulated from past events no longer producing active growth
- Visual inspection is highly subjective and examiner-dependent

This finding supports the use of ERMI as a supplementary tool in comprehensive investigations rather than a replacement for thorough physical building assessment.

Temporal Considerations

Settled dust in carpets accumulates over weeks to months, meaning ERMI results reflect the integrated mold burden over a period of time rather than conditions on a single day. Vesper et al. (2022) assessed post-hurricane sanitized homes and found that it takes several weeks (greater than 25 days) for ERMI-like values to significantly reduce and stabilize (Vesper, Libuit, Esguerra, & Cross, 2022). This is both an advantage (reduces sampling variability) and a limitation (results may not reflect the current status if remediation or source removal has occurred). Post-remediation testing using ERMI or HERTSMI-2 may require a month or more after completion to allow dust to resettle.

Research by Kamal et al. (2014) demonstrated reasonable ERMI repeatability for floor dust samples collected from the same homes one to seven months apart, with results that were consistent and without systematic bias — supporting the temporal stability of the measure in stable environments (Kamal, et al., 2014).

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ERMI Water-Damage Indicator Molds by Water Activity (Table 1)

The 26 ERMI Group 1 (water-damage indicator) species grouped by water-activity (aw) requirement. Values are approximate minimums for growth reported in the mycology literature and vary by substrate and study; treat the bands a a gradient rather than hard cutoffs.

Species	Approximate minimum water activity (a_w)
Xerophilic / primary colonizers (minimum $a_w \approx 0.71$-0.80) – establish on high humidity or slightly damp material	
Wallemia sebi	0.69–0.75
Eurotium (Aspergillus) amstelodami	0.70–0.76
Aspergillus penicillioides	0.73–0.77
Aspergillus restrictus	0.75
Aspergillus versicolor	0.78
Aspergillus sydowii	0.78–0.80
Penicillium brevicompactum	0.78–0.81
Penicillium variabile	0.78–0.80
Penicillium spinulosum	0.80
Moderate / secondary colonizers (minimum $a_w \approx 0.80$-0.90) – need sustained dampness	
Aspergillus ochraceus	0.77–0.80
Aspergillus flavus	0.78–0.80
Aspergillus niger	0.77–0.83
Aspergillus sclerotiorum	0.80
Aspergillus unguis	0.80
Penicillium corylophilum	0.80–0.85
Penicillium crustosum	0.80–0.85
Cladosporium sphaerospermum	0.82–0.88
Penicillium purpurogenum	0.85
Scopulariopsis brevicaulis	0.85–0.90
Scopulariopsis chartarum	0.85–0.90
Paecilomyces variotii	0.84–0.90
Hydrophilic / tertiary colonizers (minimum $a_w \geq$ ~0.90) – require actual liquid-water intrusion	
Aspergillus fumigatus	0.85–0.90
Aureobasidium pullulans	0.89–0.90
Trichoderma viride	0.90–0.93
Chaetomium globosum	0.90–0.94
Stachybotrys chartarum	0.94

Notes: A few species sit near a boundary: A. ochraceus and A. flavus are borderline xerophilic, and A. fumigatus is borderline hydrophilic. The aw figures are minimums for growth, not optima - most of these molds grow fastest well above 0.90. The ERMI panel itself does not assign aw values; species are classified here using standard colonizer categories from the mold-remediation literature.

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Epidemiological Evidence Linking ERMI to Health Outcomes

The strongest body of evidence linking ERMI values to health outcomes concerns childhood asthma. Multiple epidemiological studies across geographically diverse U.S. cities have demonstrated statistically significant associations between elevated home ERMI values and asthma diagnosis, development, or severity:

- Detroit, MI: Homes of severely asthmatic children had significantly higher ERMI values than comparison homes (Vesper, et al., 2008)
- Chapel Hill, NC: Asthmatic children's homes showed elevated ERMI scores compared to controls (Vesper, et al., 2007)
- Cincinnati, OH: ERMI values correlated with asthma outcomes in prospective cohort studies (Reponen, et al., 2011)
- Northern California (adult cohort): Homes of adults with asthma or rhinitis had significantly higher ERMI values than regional comparison homes (Blanc, et al., 2013)

A 2013 study by Vesper et al. specifically examined the correlation between ERMI values and pulmonary function testing (FEV1%) in asthmatic children, finding that children living in high-ERMI homes had measurably reduced forced expiratory volume – a clinically objective respiratory health metric (Vesper, Wymer, Kennedy, & Grimsley, 2013).

A synthesis by Vesper (2025) noted several epidemiological studies consistently demonstrated that both children and adults with asthma resided in homes with significantly higher ERMI values than control homes. The author also acknowledged the important methodological limitation that these associations demonstrate correlation, not causation (Vesper S. , The Development and Application of the Environmental Relative Moldiness Index (ERMI), 2025).

ERMI in Non-Residential Settings

While the ERMI was developed and validated for residential settings, it has been applied – with important caveats – to schools, daycares, and other non-residential buildings. Although the national reference scale is derived from homes and there are no national sampling of schools or other large buildings to create a relative comparison like there is for homes, Vesper et al. (2025) have found the home scale to be useful for comparisons of buildings or parts of buildings. For example, Vesper et al. (2018) conducted a comparative study of two identical (in terms of design) four-story buildings using the ERMI to compare relative levels of mold contamination. There were health complaints in one building, but none in the other building. The average ERMI value in the building with health complaints was 5.33 which was significantly greater than the average ERMI value, 0.55, in the non-complaint building. In another study of a large building, mold contamination was evaluated on levels of 6 to 19 of an office building with a history of water problems and health complaints. The water leaks were discovered and the health complaints were confined to the upper five stories. The average ERMI value on level 17 was 5.66 but only -0.58 on level 8. The higher ERMI values were associated with floors with occupant health complaints. Therefore, the ERMI metric appears to provide useful information about mold contamination on a relative basis for schools and other large building, in addition to homes (Vesper, Cox-Ganser, Wymer, & Park, 2018; Vesper S. , 2025).

International Applications

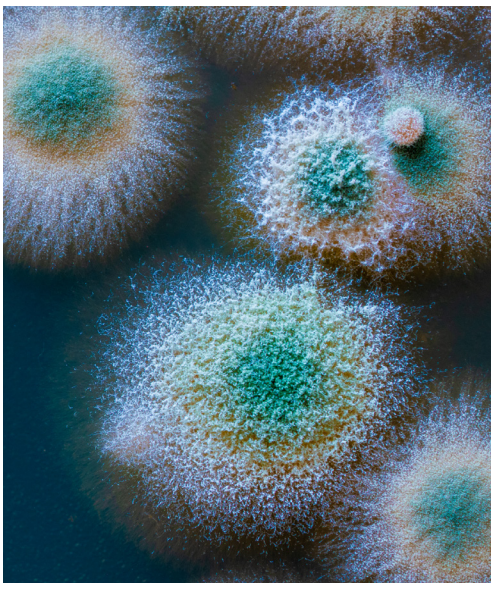
The ERMI methodology has been applied in European research settings – notably in France (Meheust, et al., 2012) and Finland (Taubel, et al., 2016) – where investigators found meaningful correlations between ERMI values and other moisture/mold assessment metrics. However, researchers attempting to apply the national ERMI scale found that geographic and climatic differences between the U.S. and European housing stock required modification of species groupings and thresholds. Finnish investigators, for example, developed a simplified, localized version of the index adapted to Finnish conditions.

These international applications demonstrate the scientific robustness of the MS-qPCR methodology while also highlighting the limitations of the U.S.-anchored reference scale when applied to non-U.S. housing populations.

Limitations

Because the ERMI dataset is dust-based and reflects historical accumulation, it does not directly measure:

- Current airborne mold exposure or spore concentrations – dust reflects what has settled over time.
- Active mold growth or viability – qPCR detects DNA, from live or dead spores/cells.
- All possible mold species or fungi – only 36 indicator species are used; many other fungal species common indoors are not captured.
- Mold toxins, allergens, or other health-relevant factors – ERMI reports DNA-based presence, not toxin production or allergenic potential.
- Absolute "safe or unsafe" thresholds – ERMI is a relative index based on a reference sample, a "low" or "high" ERMI simply indicates relative mold burden, not guaranteed safety or risk.



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Furthermore, in follow-up sampling (AHHS II), researchers found homes built before 1978 tended to have higher ERMI scores on average than newer homes, suggesting that home age (and likely building materials/maintenance, plumbing/roof age, etc.) strongly affects mold burden (Vesper, et al., 2021) . Finally, dust sampling inherently depends on where and how dust was collected (floor vs. other surfaces; frequency of cleaning; occupant behavior), so variability in dust sampling can influence results.

EPA's Position on Public Use of the ERMI Scale

Although the ERMI assessment has been used by EPA to help characterize relative levels of mold contamination in homes and other buildings and is being used to investigate potential relationships between ERMI values and health effects. In EPA's studies to date, higher ERMI values in homes have been correlated with a greater likelihood of occupant asthma. As the approach has not been validated through a multi-lab study, the EPA cannot comment on the accuracy of information obtained from others using ERMI. Inspection for water damage and mold remain the key to current EPA mold-assessment guidance (U.S. EPA, 2021).

Practical Applications in Industrial Hygiene and Mold Assessment Surveys

Despite its limitations, the ERMI remains the only standardized, DNA-based national reference tool for quantifying the relative water-damage mold burden in U.S. homes. Appropriate applications include:

- Epidemiological research comparing mold burden across populations of homes
- Hypothesis generation in building investigations – identifying whether a home's mold burden is notably above the national norm before committing to more invasive investigation
- Supplement to a comprehensive investigation that also includes visual inspection, moisture mapping, bulk sampling, and building history review
- Pre- and post-remediation comparison within the same building (using the same collection method) to assess change over time
- Exposure classification in health effects studies where individual-level precision is less critical than population-level differentiation

The most defensible application of ERMI data – whether in forensic investigations, occupational health consulting, or property assessments – is as one tool within a multi-method assessment framework that includes:

- Moisture investigation protocols
- Visual and olfactory inspection by a qualified industrial hygienist or certified (and/or licensed) mold assessment consultant
- Thermal imaging and moisture meter mapping to identify areas of elevated moisture content
- Air sampling (spore-trap or impactor plate) for concurrent airborne mold characterization
- Bulk/surface sampling and culture/microscopy of suspect materials
- Building history review (water intrusion events, prior remediation, material changes)
- Occupant health history in the context of building-related illness claims



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