The environmental relative moldiness index (ERMI) metric was previously developed to quantify mold contamination in U.S. homes. This study determined the applicability of the ERMI for quantifying mold and moisture damage in Finnish residences. Homes of the LUKAS2 birth cohort in Finland were visually inspected for moisture damage and mold, and vacuumed floor dust samples were collected. An ERMI analysis including 36 mold-specific quantitative PCR assays was performed on the dust samples (n = 144), and the ERMI metric was analyzed against inspection-based observations of moisture damage and mold. Our results show that the ERMI was significantly associated with certain observations of visible mold in Finnish homes but not with moisture damage. Several mold species occurred more frequently and at higher levels in Finnish than in U.S. homes. Modification of the ERMI toward Finnish conditions, using a subsample of LUKAS2 homes with and without moisture damage, resulted in a simplified metric based on 10 mold species. The Finnish ERMI (FERMI) performed substantially better in quantifying moisture and mold damage in Finnish homes, showing significant associations with various observations of visible mold, strongest when the damage was located in the child’s main living area, as well as with mold odor and moisture damage. As shown in Finland, the ERMI as such is not equally well usable in different climates and geographic regions but may be remodeled to account for local outdoor and indoor fungal conditions as well as for moisture damage characteristics in a given country.

Moisture problems in Finnish homes are common. A study relying on standardized building inspections reported signs of current or previous moisture fault in 80% of residences, with >50% of these homes being in need of repair (1). A more recent analysis from a Finnish cohort confirmed that >70% of homes would be in need of repair beyond just esthetic interventions, and mold was visually observed in 38% of these homes (2). Moisture problems appear to be prevalent also in Finnish schools (3). This implies a need to prioritize renovation actions based on the severity or extent of the moisture problem and/or the related health hazard. Exposure to water-damaged, moldy buildings has been linked to both exacerbations and development of asthma (4–8). Identifying and quantifying “abnormal” mold exposures might be critical in efforts to reduce the disease burden of asthma due to dampness and moisture damage in buildings.

Many techniques have been used to estimate mold contamination in homes, but self-reporting of visual observations is the most commonly used method. A visual assessment, often supported by microbial verification of damage situations, can be accurate if performed by an experienced building inspector or engineer and in such cases can be considered the current gold standard for assessing indoor mold. However, not everyone performing visual inspections is equally qualified, and mold contamination can be hidden from sight inside structures (9). Moreover, in large epidemiological studies, detailed building inspections are typically not feasible.

Currently, cultivation-based detection of viable fungi and bacteria from indoor samples such as building material or air samples is the most commonly used method for quantifying microbes in support of building investigations. The cultivation-based approach has drawbacks, however, including extended analysis durations, limited reproducibility (especially considering short-term air samples), and the fact that only the alive and cultivable fractions of the microbial spectrum are visualized. In conclusion, there is a need for improved and objective metrics for quantifying mold contamination in homes.

The U.S. Environmental Protection Agency (EPA) together with the U.S. Department of Housing and Urban Development established a metric to quantify mold contamination in U.S. homes, called the environmental relative moldiness index (ERMI) (10). For ERMI analysis, a DNA-based technology, mold-specific quantitative PCR (qPCR) (MSQPCR), is used to measure the concentrations of 36 indicator molds in floor dust samples. Of the 36 molds, 26 are group 1 species commonly found at higher levels in water-damaged homes and 10 are group 2 species commonly found in U.S. homes, independent of water damage (11).

The ERMI metric has been used in many studies in the United States as a predictor of moisture damage, mold contamination, and asthma (12–15). The ERMI has also been applied in a few studies outside the United States (16–18). However, the categorization of the ERMI mold species and groups into water damage (group 1) and normal background (group 2) molds was developed in a restricted sample of moisture-damaged and reference homes in a confined geographical area in the United States (Cleveland, OH) (11). Thus, the applicability of the ERMI metric in different countries or regions with differences in climatic conditions, building stocks, and characteristics of moisture damage and mold con-
tamination needs to be explored. The purpose of this analysis of homes of a Finnish birth cohort (19) was to determine if the ERMI metric might be applied to quantifying moisture damage and mold contamination in Finnish homes.

**MATERIALS AND METHODS**

**Study population.** The LUKAS2 study is an ongoing birth cohort study in Eastern Finland, with the mothers of the study subjects recruited at Kuopio University hospital (20). The mothers were monitored from the third trimester of pregnancy, and children were born between May 2004 and May 2005. Written informed consent was obtained from the parents; all study protocols for the LUKAS2 study were approved by a local ethics committee in Finland (20). The cohort consists of a general population sample of homes in rural and suburban areas in this region, excluding high-rise apartment buildings. A total of 199 dust samples were collected during early childhood; 144 of these samples were included in this analysis, based on following criteria: sufficient dust was available for DNA extraction and qPCR analyses, corresponding results from home inspection were available, the families had lived in the same home at the time of home inspection and dust vacuuming, and the homes were nonfarming homes.

**Home inspection for dampness and mold.** During early childhood (mean child age, 9 months), a building engineer performed detailed “walkthrough” inspections of the study homes to assess moisture damage, visible mold, and other dampness indicators, as previously described in detail (2, 19). The inspections were performed according to a standardized protocol (1) and by utilizing standardized checklists and questionnaires (5). In brief, visual observations in individual rooms and areas of the home (bedroom, living room, kitchen, and bathroom, etc.) were complemented by recording of surface moisture, visible mold, and mold odor. Damage observations were graded based on extent and severity. The inspector recorded detailed estimates of individual damage in each location separately and also made an overall assessment of the whole house. A 6-point “need-for-repair” scale (1) was used to grade the severity of moisture damage both for individual observations and, on a more general basis, for the house as a whole: classes 0 and 1 refer to damage with no need for repair or only cosmetic repair, class 2 means that repair of surface materials is needed, class 3 indicates that repair of structural components is needed, and classes 4 and 5 call for more extensive repairs due to moisture problems.

“Moisture damage” was categorized into three levels (none, minor, or major) by combining the 6-point need-for-repair estimation scale (1) and the area of damage (5). “No damage” was defined as need-for-repair class 0 or 1. “Major damage” was defined as need-for-repair class 2 and an area of damage of ≥0.1 m², need-for-repair class 3 with an area of damage of ≥0.1 m², or need-for-repair class 4 or 5. Damage other than those described above was classified as “minor damage.” In the case of several damage observations in a given location, the areas of damage with same need for repair were summed up. “Visible mold” was categorized as “yes” (observation of moisture damage with mold spots only or with more extensive visible mold) or “no” (no observed moisture damage with visible mold). Mold on silicone sealants in the kitchen or in the bathroom only was classified as no mold. “Mold odor” was categorized as “no odor,” “slight odor,” or “odor.” Combination variables of observations made in the “child’s main living areas” were created, combining moisture damage or visible mold observations for the child’s bedroom, living room, and kitchen.

**Dust sample collection and MSQPCR analysis.** The protocol for dust collection was described previously (20). Parents took samples from living room floors of homes of the children when the children were ~1 year old. The dust sample was vacuumed from a 1-m² area of a rug for 2 min (in cases where there was no rug in the living room, the sample was taken from a 4-m² area of smooth floors for 2 min), using a regular vacuum cleaner and polyester dust sampling socks (Allied Filter Fabrics Pty. Ltd., Australia). The dust samples were processed at the National Institute of Health and Welfare in Finland, where they were stored in the dark at 4°C prior to sieving and then kept in a desiccator for 2 days. The dust samples were then stored frozen at −20°C until shipment on dry ice to the U.S. EPA.

Each dust sample was sieved through a 300-µm-pore-size nylon mesh (Gilson Company, Inc., Lewis Center, OH), and 0.0 ± 0.1 mg of sieved dust was then extracted and DNA was purified by using the DNA-EZ extraction kit (GeneRite, Monmouth Junction, NJ), according to the manufacturer’s instructions. The concentration of each mold was determined by MSQPCR analysis (21). The standard reaction assay mixtures contained 12.5 µl of Universal master mix (Applied Biosystems, Inc., Foster City, CA), 1 µl of a mixture of forward and reverse primers at 25 µM each, 2.5 µl of 400 nM TaqMan probe (Applied Biosystems, Inc.), 2.5 µl of 2 mg/ml of fraction V bovine serum albumin (Sigma Chemical, St. Louis, MO), and 2.5 µl of DNA-free water (Cepheid, Sunnyvale, CA). Five microliters of the DNA extract from the sample was added to this mix. All primer and probe sequences used in the assays were reported previously (22). Primers and probes were synthesized commercially (Applied Biosystems, Inc.).

The ERMI value for each home was calculated by taking the sum of the logs of the concentrations of the 26 group 1 species (S₁) and subtracting the sum of the logs of the concentrations of 10 group 2 species (S₂) (10):

\[
ERMI = \sum_{i=1}^{26} \log_{10}(S_{i}) - \sum_{j=1}^{10} \log_{10}(S_{j})
\]

| Area of home                  | Visible mold and ERMI | Moisture damage and ERMI |
|------------------------------|-----------------------|--------------------------|
|                              | Detection | No. of homes | ERMI | P value | Detection | No. of homes | ERMI | P value |
| Living room                  | No        | 141         | 5.43 | 0.52    | None      | 128         | 5.27 |         |
|                              | Yes       | 3           | 10.24|         | Minor     | 12          | 7.45 |         |
|                              |           |             |      |         | Major     | 4           | 8.22 | 0.21    |
| Child’s main living area     | No        | 134         | 5.22 |         | None      | 102         | 5.35 |         |
|                              | Yes       | 10          | 9.72 | 0.007   | Minor     | 31          | 5.22 |         |
|                              |           |             |      |         | Major     | 11          | 8.12 | 0.22    |
| Whole house                  | No        | 100         | 5.14 | 0.17    | Class 0/1 | 60           | 5.16 |         |
|                              | Yes       | 44          | 6.42 |         | Class 2   | 50           | 5.72 |         |
|                              |           |             |      |         | Class ≥3  | 34           | 5.90 | 0.76    |

a Differences in the mean ERMI values were evaluated by using a t test or one-way ANOVA.

b Mean ERMI value.
Comparison of ERMI molds in Finland and the United States. The occurrence (percentage of samples in which the mold was detected) and population geometric mean (GM) for each of the 36 ERMI molds in these homes in Finland were compared to the occurrence and population GM for these same molds in homes in the United States, using data that were previously reported (10).

Development of the FERMI. In order to adapt the ERMI metric and improve its applicability to local conditions in Finland, we selected a subsample of LUKAS2 homes with severe moisture damage (i.e., moisture-damaged homes [MDHs]) (n = 20) and reference homes (RHs) (n = 42) that had no signs of moisture damage in any room of the house. Severe moisture damage was defined as major moisture damage, visible mold, and/or mold odor in the main living areas (i.e., kitchen, living rooms, bedrooms, and main hallways connecting these rooms). As in the definitions of the original ERMI, we (i) included only mold species (i.e., qPCR assays) with a mean value in these 62 homes of ≥1 conidium per 5 mg of dust (based on this criterion, Aspergillus unguis was excluded from further analyses) and (ii) calculated geometric mean ratios for moisture-damaged versus reference homes for 35 individual mold species to define group 1 (moisture damage-associated) and group 2 (background) mold species.

Statistical analysis. Geometric means were calculated from log-transformed qPCR results; zero values in qPCR data were also recorded as zero values in the log-transformed data set. ERMI and FERMI values were normally distributed, and thus, a t test or one-way analysis of variance (ANOVA) was used to compare mean values for moisture damage indicators in the sample of 144 LUKAS2 study homes. The analyses were performed with SAS version 9.3 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

In this analysis, we show a basic agreement of the environmental relative moldiness index (ERMI) with inspection-confirmed, visible mold observations in Finnish homes but not with moisture damage. We demonstrate a substantial improvement of this metric by adapting it to local conditions by redefining what can be considered moisture damage and background molds based on sets of severely moisture-damaged homes and reference homes in Finland.

The ERMI has been developed to quantify mold contamination in homes in the United States (10). It is a metric that is based on quantitatively measured mold species or groups that are either linked to conditions of moisture and mold damage or considered normal background molds, with these definitions being based on a sample of U.S. homes (11). By integrating a large number of different mold taxa potentially linked to moisture damage, the ERMI metric takes into account the complexity of microbial exposure situations and acknowledges the fact that no two moisture-damaged homes are identical in terms of their extent and profile of microbial contamination (23). This approach also factors in the content of mold species that are commonly observed in homes independent of moisture or mold damage and by doing so adjusts for high fungal levels in homes that are not linked to moisture problems but rather are related to outdoor or other sources.

The ERMI metric has been applied to many studies of mold contamination and also of occupant asthma in U.S. homes (12–15). While the ERMI has not been tested or reported extensively in countries outside the United States, the metric has been shown to be useful in studies of mold contamination in some European countries, including the United Kingdom, specifically Scotland (18), and France (16). This study is the first to explore the applicability of the ERMI in Finland, in a Northern climate.

The mean ERMI values were generally higher in Finnish homes where visible mold or moisture damage was observed than in homes without such observations. However, the ERMI was statistically significantly higher (P = 0.007) only if there was visible mold in the child’s main living areas, but other associations, especially with minor or major moisture damage, did not reach statistical significance (Table 1). These findings indicate that while the ERMI metric responds to increases or changes in microbial content due to moisture problems in a Finnish home, a clear numerical response in this assessment can be observed only in very severe cases that manifest as visible mold growth. Floor dust samples for ERMI determination were collected in the living room; the definition of the “child’s main living area” includes the living room, the area next to the child’s bedroom, and the kitchen area in the home. Thus, it is conceivable that visible mold observed in the

### Table 2 Comparison of the occurrences and geometric mean cell equivalents per milligram for the 36 ERMI molds in LUKAS2 homes in Finland (n = 144) compared to U.S. homes (n = 1,096)<sup>a</sup>

| Mold                        | % occurrence | GM concn (cell equivalents/mg) |
|-----------------------------|--------------|---------------------------------|
|                             | Finland      | U.S.                            |
|                             | Finland      | U.S.                            |
| Group 1                     |              |                                 |
| Aspergillus flavus          | 44           | 36                              |
| Aspergillus fumigatus       | 44           | 62                              |
| Aspergillus niger           | 67           | 69                              |
| Aspergillus ochraceus       | 38           | 27                              |
| Aspergillus penicillioides  | 95           | 90                              |
| Aspergillus restrictus      | 95           | 12                              |
| Aspergillus sclerotiorum    | 5            | 26                              |
| Aspergillus sydowii         | 15           | 29                              |
| Aspergillus unguis          | 6            | 20                              |
| Aspergillus versicolor      | 13           | 30                              |
| Aureobasidium pullulans     | 100          | 94                              |
| Chaetomium globosum         | 44           | 51                              |
| Cladosporium sphaerospermum | 88           | 82                              |
| Eurotium anastomadani      | 100          | 98                              |
| Paecilomyces variotii       | 31           | 46                              |
| Penicillium brevicaempactum | 98           | 52                              |
| Penicillium corylophilum    | 50           | 17                              |
| Penicillium crustosum group | 43           | 8                               |
| Penicillium purpureogenum   | 19           | 15                              |
| Penicillium spinulosum      | 22           | 20                              |
| Penicillium varie           | 31           | 50                              |
| Scopulariopsis brevicaulis  | 66           | 53                              |
| Scopulariopsis chartarum    | 52           | 38                              |
| Stachybotrys chartarum      | 24           | 35                              |
| Trichoderma viride          | 95           | 27                              |
| Wallenia sebi               | 98           | 75                              |

| Group 2                     |              |                                 |
| Acremonium strictum         | 82           | 57                              |
| Alternaria alternata        | 96           | 88                              |
| Aspergillus ustus           | 28           | 40                              |
| Cladosporium cladosporoides type 1 | 100   | 99                            |
| Cladosporium cladosporoides type 2 | 100   | 70                            |
| Cladosporium herbarum       | 100          | 84                             |
| Epicoccum nigrum            | 100          | 93                             |
| Mucor group                 | 99           | 92                             |
| Penicillium chrysogenum     | 38           | 66                             |
| Rhizopus stolonifer         | 53           | 29                             |

<sup>a</sup> See reference 10.
child’s main living area correlates strongly with the ERMI metric. The fact that visible mold observed in the living room, however, failed to statistically significantly increase the living room floor dust ERMI can be explained by the low number of observations of visible mold in living rooms (n/H11005 3) in this study, heavily limiting the statistical power in calculating these associations.

We observed considerable differences in the profiles of mold species, analyzed in the same laboratory, by comparing the results from the Finnish LUKAS2 cohort to the results of a large national survey in the United States (10). The occurrences and population geometric means for each of the 36 ERMI molds for the Finnish homes compared to those for 1,096 U.S. homes are shown in Table 2. These differences in prevalence and levels of different mold species that constitute the ERMI likely contribute to why a mold scale developed in the United States does not predict indoor mold conditions in Finland equally well. Molds with GM levels at least 10 times higher in Finnish homes than in U.S. homes included four ERMI group 1 (moisture damage) species, Aspergillus restrictus, Aureobasidium pullulans, Penicillium brevicompactum, and Trichoderma viride, and two ERMI group 2 (background) species, Cladosporium cladosporioides (Type 1) and Cladosporium herbarum. Aspergillus penicillioides had a GM level that was 10 times higher in the United States than in Finland (Table 2).

### TABLE 3 Original ERMI mold species (group 1 and group 2) measured in floor dust from a sample of Finnish homes in the LUKAS2 cohort with severe moisture damage (MDHs) and nondamaged reference homes (RHs)\(^a\)

| Mold                        | Prevalence (\% samples > DL)\(^b\) | GM concn. (no. of conidia/5 mg) | GM ratio of MDHs/RHs | All samples (all seasons) (20/42) | Samples taken during snow cover (4/13) | Samples taken during no snow cover (16/29) |
|-----------------------------|------------------------------------|---------------------------------|----------------------|-----------------------------------|----------------------------------------|------------------------------------------|
| **ERMI group 1**            |                                    |                                 |                      |                                   |                                        |                                          |
| Aspergillus flavus          | 47                                 | 1.48                            | 1.53                 | 0.96                              | 0.85                                   | 0.99                                     |
| Aspergillus fumigatus       | 50                                 | 2.06                            | 2.38                 | 0.87                              | 1.09                                   | 0.80                                     |
| Aspergillus niger           | 77                                 | 5.65                            | 5.45                 | 1.04                              | 1.32                                   | 0.92                                     |
| Aspergillus ochraceus       | 39                                 | 6.27                            | 2.42                 | 2.59                              | 3.30                                   | 2.53                                     |
| Aspergillus penicillioides  | 97                                 | 3.90                            | 4.39                 | 0.89                              | 2.02                                   | 0.67                                     |
| Aspergillus restrictus      | 97                                 | 1,503.68                        | 1,171.24             | 1.28                              | 6.80                                   | 0.99                                     |
| Aspergillus sclerotiorum    | 6                                  | 1.04                            | 1.12                 | 0.92                              | 0.83                                   | 0.96                                     |
| Aspergillus sydowii         | 16                                 | 1.26                            | 1.20                 | 1.06                              | 0.81                                   | 1.14                                     |
| Aspergillus versicolor      | 19                                 | 2.70                            | 1.30                 | 2.08                              | 1.48                                   | 2.18                                     |
| Aureobasidium pullulans     | 100                                | 4,355.01                        | 4,562.12             | 0.95                              | 3.16                                   | 0.57                                     |
| Chaetomium globosum         | 47                                 | 2.35                            | 1.57                 | 1.50                              | 0.95                                   | 1.77                                     |
| Cladosporium sphaerospermum| 85                                 | 10.93                           | 4.55                 | 2.40                              | 18.40                                  | 1.43                                     |
| Eurotium anastomadonti     | 95                                 | 22.32                           | 21.63                | 1.03                              | 4.00                                   | 0.83                                     |
| Paeclonycyes varioti       | 37                                 | 1.34                            | 1.53                 | 0.88                              | 1.14                                   | 0.79                                     |
| Penicillium brevicompactum  | 98                                 | 169.09                          | 323.15               | 0.52                              | 1.31                                   | 0.48                                     |
| Penicillium corylophilum    | 50                                 | 3.59                            | 1.87                 | 1.92                              | 1.78                                   | 1.93                                     |
| Penicillium crustosum       | 50                                 | 8.51                            | 5.09                 | 1.67                              | 2.16                                   | 1.70                                     |
| Penicillium purpurogenum    | 26                                 | 1.13                            | 1.35                 | 0.84                              | 0.63                                   | 0.93                                     |
| Penicillium spinulosum      | 31                                 | 0.84                            | 0.96                 | 0.88                              | 0.89                                   | 0.87                                     |
| Penicillium variabile       | 31                                 | 1.20                            | 1.25                 | 0.95                              | 0.90                                   | 0.95                                     |
| Scopulariotisp breviscudus  | 71                                 | 0.86                            | 0.91                 | 0.94                              | 1.81                                   | 0.76                                     |
| Scopulariotisp chartarum    | 63                                 | 3.49                            | 3.25                 | 1.08                              | 2.79                                   | 0.79                                     |
| Stachybotrys chartarum      | 24                                 | 1.73                            | 1.24                 | 1.40                              | 2.45                                   | 1.16                                     |
| Trichoderma viride          | 97                                 | 114.74                          | 113.91               | 1.01                              | 1.16                                   | 1.18                                     |
| Wallenia sebi               | 100                                | 209.22                          | 203.15               | 1.03                              | 9.77                                   | 0.55                                     |
| **ERMI group 2**            |                                    |                                 |                      |                                   |                                        |                                          |
| Acremonium strictum         | 87                                 | 4.06                            | 3.85                 | 1.05                              | 2.89                                   | 0.78                                     |
| Alternaria alternata        | 95                                 | 15.89                           | 17.72                | 0.90                              | 0.71                                   | 0.91                                     |
| Aspergillus ustus           | 27                                 | 1.54                            | 1.58                 | 0.97                              | 1.46                                   | 0.87                                     |
| Cladosporium cladosporioides| 100                                | 3,506.15                        | 6,355.21             | 0.55                              | 0.99                                   | 0.40                                     |
| Cladosporium cladosporioides| 200                                | 26.10                           | 19.14                | 1.36                              | 1.16                                   | 1.42                                     |
| Cladosporium herbarum       | 100                                | 1,705.70                        | 2,924.37             | 0.58                              | 1.23                                   | 0.41                                     |
| Epicoccum nigrum           | 100                                | 43.13                           | 86.63                | 0.50                              | 0.29                                   | 0.45                                     |
| Mucor group                | 98                                 | 60.50                           | 37.42                | 1.62                              | 8.86                                   | 0.88                                     |
| Penicillium chrysogenum     | 42                                 | 3.13                            | 1.92                 | 1.63                              | 3.24                                   | 1.40                                     |
| Rhizopus stolonifer         | 50                                 | 1.84                            | 1.83                 | 1.00                              | 1.80                                   | 0.93                                     |

\(^a\) Presented are percent prevalences, geometric mean concentrations of 35 mold species, GM ratios (MDHs/RHs) for all samples, and GM ratios separately for samples collected during periods of permanent snow cover (January to March) and non-permanent snow cover (April to December).

\(^b\) > DL, above the detection limit.
TABLE 4 The Finnish environmental moldiness index

| Mold                              | GM ratio (MDHs/RHs) | Prevalence (%) in:                                                                 |
|-----------------------------------|---------------------|----------------------------------------------------------------------------------|
|                                   |                     | FERMI group 1                                                                      |
| Aspergillus ochraceus              | 2.59                | 65 31                                                                             |
| Aspergillus versicolor             | 2.08                | 30 14                                                                             |
| Chaetomium globosum               | 1.50                | 45 48                                                                             |
| Cladosporium sphaerospermum       | 2.40                | 90 83                                                                             |
| Penicillium corylophilum          | 1.92                | 60 45                                                                             |
| Penicillium crustosum             | 1.67                | 55 48                                                                             |
| Penicillium chrysogenum           | 1.65                | 45 41                                                                             |
|                                   |                     | FERMI group 2                                                                      |
| Alternaria alternata              | 0.90                | 95 95                                                                             |
| Cladosporium cladosporoides type 1| 0.55                | 100 100                                                                          |
| Epicoccum nigrum                 | 0.50                | 100 100                                                                          |

a Shown are data for the mold species/group qPCRs that constitute FERMI groups 1 and 2, their GM ratios, and proportions with detectable levels in homes with severe moisture damage (n = 20) versus reference homes without observed moisture damage or mold (n = 42). 

TABLE 5 Comparison of mean FERMI values for LUKAS2 homes in which observations of visible mold or more generally moisture damage were made in the living room, the child’s main living areas, or the whole house

| Area in home                  | Visible mold and FERMI Detection | No. of homes | FERMI Value | P value | Moisture damage and FERMI Detection | No. of homes | FERMI Value | P value |
|-------------------------------|----------------------------------|--------------|-------------|---------|-------------------------------------|--------------|-------------|---------|
| Living room                   | No                                | 141          | 5.33        |         | None                                | 128          | 4.98        |         |
|                               | Yes                               | 3            | 15.20       | 0.007   | Minor                               | 12           | 11.10       |         |
|                               |                                   |              |             |         | Major                               | 4            | 6.53        | 0.01    |
| Child’s main living area      | No                                | 134          | 4.92        |         | None                                | 102          | 4.85        |         |
|                               | Yes                               | 10           | 13.69       | <0.0001 | Minor                               | 31           | 6.30        |         |
|                               |                                   |              |             |         | Major                               | 11           | 9.70        | 0.04    |
| Whole house                   | No                                | 100          | 4.51        |         | Class 0/1                            | 60           | 3.81        |         |
|                               | Yes                               | 44           | 7.85        | 0.003   | Class 2                              | 50           | 5.91        |         |
|                               |                                   |              |             |         | Class ≥3                             | 34           | 8.02        | 0.007   |

a Differences in the mean FERMI values were evaluated by using a t test or one-way ANOVA. 
b Mean FERMI value.
FIG 1 Box plots of ERMI and FERMI values for LUKAS2 homes based on their overall need for repair due to moisture damages. Homes are categorized into need-for-repair class 0 or 1 (no need for repair or only esthetic repairs) ($n = 60$), class 2 (repair of surface materials needed) ($n = 50$), and class 3 or higher (repair of structural components or more extensive repairs needed) ($n = 34$). Boxes represent 25th, 50th, and 75th percentiles; whiskers are 5th and 95th percentiles. ***, $P$ value of $<0.05$ according to Scheffé’s pairwise analysis.

cover and clearly $<1$ during non-snow cover or vice versa); and
(iii) including only such mold species as background molds in
group 2 that showed no association with moisture damage (GM
ratio of $\leq 1$) independent of season and that were well prevalent
($>50\%$) in the house dust samples (Table 3).

By doing so, we created the FERMI metric, which consists of
10 mold species (7 group 1 molds and 3 group 2 molds) (Table
4). The calculation of the FERMI followed the original ERMI
approach (see Materials and Methods). In order to keep the
majority of FERMI values positive and somewhat numerically
comparable with the initial ERMI scale, we adjust here for the
mean numerical difference of the FERMI versus ERMI in Finn-
ish LUKAS2 homes (14.42) and add this value to the equation
of the FERMI:

$$ \text{FERMI} = \sum_{i=1}^{10} \log_{10}(S_i) - \sum_{j=1}^{3} \log_{10}(S_j) + 14.42$$

When applied to the full sample of 144 homes from the
LUKAS2 cohort, the FERMI metric was found to be significantly
associated with observations of visible mold in various locations
and—this being a clear improvement compared to the original
ERMI metric—also with observations of moisture damage in the
living room, the child’s main living areas, and the whole house
(Table 5) as well as with mold odor observed in the whole house
(data not shown). Relating to the need for repair in the house, a
scale which is based on the severity of moisture problems assessed
during the building inspection, the FERMI, unlike the ERMI,
showed a significant dose-response association (Fig. 1).

The season of dust sampling did not change the significance
of associations observed between the FERMI and different
moisture damage and dampness indicators in most cases. We
did, however, observe significantly higher FERMI and ERMI
values for winter than for nonwinter samples (differences in
means were 3.3 and 3.4 points, respectively). This finding is
likely explained by a great reduction of outdoor mold (group 2)
Sources during winter (29) but not of indoor sources and mois-
ture damage-related molds (group 1), which results in a higher
(F)ERMI value. This observation is relevant for future studies
that apply the ERMI or FERMI to sample materials collected
during different seasons, especially in countries with distinct
seasonal differences in their climates.

The results of our study are encouraging in that the FERMI
appears to be a promising tool to confirm inspection-based obser-
vations of mold and moisture damage in homes in Finland in an
objective way. Our study is limited to a cohort of 144 homes lo-
cated in Eastern Finland, and the definition of the FERMI was
made based on a subsample ($n = 62$) of these homes. Thus, our
findings will have to be confirmed in other studies in Finland,
before application of the FERMI in research or practical settings
can be recommended. Also, the focus of this study was on quan-
tifying moisture damage and mold contamination. The applica-
bility of the FERMI metric to predict respiratory symptoms and
the development of asthma due to indoor mold contamination in
Finland, similar to what has been done for the ERMI in U.S.
homes (12–15), will be the objective of future research efforts.

In conclusion, we show here that remodeling of the ERMI scale
to account for local microbial flora and moisture damage charac-
teristics in Finland resulted in a metric with greater potential to
objectively rate homes with moisture and mold damage in this
specific setting. Following such an approach may also be applicable
to other climates, countries, or regions.

**ACKNOWLEDGMENTS**

We gratefully acknowledge the contribution of our field worker Raija
Juntunen; our civil engineer Juho Halla-aho; as well as Pekka Tiitinen,
Timo Kauppiä, and Asko Vepsäläinen for data management. We also
thank the families for their participation in the study.

The authors in Finland have no financial relationships relevant to this
article to disclose. The U.S. Environmental Protection Agency (EPA)
through its Office of Research and Development collaborated in the
research described here. Although this work was reviewed by the EPA
and approved for publication, it may not necessarily reflect official EPA policy.

Mention of trade names or commercial products does not constitute en-
dorsement or recommendation by the EPA for use. Since MSQPCR tech-
ology is patented by the U.S. EPA, the Agency has a financial interest in
its commercial use. The funders had no role in study design, data collec-
tion and interpretation, or the decision to submit the work for publica-
tion.

M.T., A.M.K., and J.P. conceived this study. J.P. is the principal inves-
tigator of the LUKAS2 cohort, and A.H. has the main responsibility for
microbial sampling and microbial analyses for this cohort. A.H. and T.R
provided valuable input for this study’s design and data analyses. S.V.
performed qPCR analyses and helped in analyses and writing of the paper.
M.T. and A.M.K. performed the statistical analyses and wrote the paper.
All authors edited and approved the final manuscript.
REFERENCES

1. Nevalainen A, Partanen P, Jääskeläinen E, Hyvärinen A, Koskinen O, Meklin T, Vahteristo M, Koivisto J, Husman T. 1998. Prevalence of moisture problems in Finnish houses. Indoor Air 8:45–49. http://dx.doi.org/10.1002/(SICI)1099-1166(199808)8:1<45::AID-INAI5>3.0.CO;2-M

2. Karvonen AM, Hyvärinen A, Korppi M, Haverinen-Shaughnessy U, Renz H, Pfefferle PJ, Remes S, Genniizet U, Pekkanen J. 2015. Moisture damage and asthma: a birth cohort study. Pediatrics 135:e598–e606. http://dx.doi.org/10.1542/peds.2014-1239

3. Haverinen-Shaughnessy U, Borras-Santos A, Turunen M, Zock JP, Jacobs J, Krop EF, Casas L, Shaughnessy R, Täubel M, Heederik D, Hyvärinen A, Pekkanen J, Nevalainen A, HITEA Study Group. 2012. Occurrence of moisture problems in schools in three countries from different climatic regions of Europe based on questionnaires and building inspections—the HITEA study. Indoor Air 22:457–466. http://dx.doi.org/10.1111/j.1600-0666.2012.00780.x.

4. Institute of Medicine, National Academies of Science. 2004. Damp indoor spaces and health. National Academies Press, Washington, DC.

5. Pekkanen J, Hyvärinen A, Haverinen-Shaughnessy U, Korppi M, Putus T, Nevalainen A. 2007. Moisture damage and childhood asthma: a population-based incident case-control study. Eur Respir J 29:509–515. http://dx.doi.org/10.1183/09031936.00040806.

6. World Health Organization. 2009. WHO guidelines for indoor air quality: dampness and mould. WHO, Copenhagen, Denmark.

7. Mendell MJ, Mirer AG, Cheung K, Tong M, Douwes J. 2011. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. Environ Health Perspect 119:748–756. http://dx.doi.org/10.1289/ehp.1002410.

8. Kanchongkittiphon W, Mendell MJ, Gaffin JM, Wang G, Phipatanakul W. 2015. Indoor environmental exposures and exacerbation of asthma: an update to the 2000 review by the Institute of Medicine. Environ Health Perspect 123:6–20. http://dx.doi.org/10.1289/ehp.1307922.

9. Vesper S, McKinstry C, Cox D, Dewalt G. 2009. Correlation between ERMI values and other moisture and mold assessments of homes in the American Healthy Homes Survey. J Urban Health 86:450–460. http://dx.doi.org/10.1177/1090023009344010.

10. Vesper S, McKinstry C, Cox D, Dewalt G. 2009. Correlation between ERMI values and moisture damage and asthma in U.S. J Occup Environ Med 51:489–833. http://dx.doi.org/10.1097/JOM.0b013e3181255e98.

11. Vesper SJ, Varma M, Wymer LJ, Dearborn DG, Sobolewski J, Haufland GR, Thomson NC. 2015. Decreased FEV1% in asthmatic adults in Scottish homes with high environmental relative moldiness index values. Clin Exp Allergy 45:902–907. http://dx.doi.org/10.1111/cea.12482.

12. Karvonen AM, Hyvärinen A, Roponen M, Hoffmann M, Korppi M, Remes S, von Mutius E, Nevalainen A, Pekkanen J. 2009. Confirmed moisture damage at home, respiratory symptoms and atopy in early life: a birth-cohort study. Pediatrics 124:e329–e336. http://dx.doi.org/10.1542/peds.2008-1590.

13. Nevalainen A, Seuri M. 2005. Microbiological and fungal asthma in children and adolescents. U.S. patent 6,387,652.

14. Vesper S, McKinstry C, Cox D, Dewalt G. 2009. Correlation between ERMI values and other moisture and mold assessments of homes in the American Healthy Homes Survey. J Urban Health 86:450–460. http://dx.doi.org/10.1177/1090023009344010.

15. Amund ASD, Seifert KA, Samson R, Bruns TD. 2010. Indoor fungal composition is geographically patterned and more diverse in temperate zones than in the tropics. Proc Natl Acad Sci USA 107:13748–13753. http://dx.doi.org/10.1073/pnas.1000451017.

16. Martiny JBH, Bohannan BJ, Brown JH, Colwell RK, Fuhrman JA, Green JL, Horner-Devine MC, Kane M, Krumins JA, Kuske CR, Morin PJ, Naem S, Overläs R, Reysenbach AL, Smith VH, Staley JT. 2006. Microbial biogeography: putting microorganisms on the map. Nat Rev Microbiol 4:112–122. http://dx.doi.org/10.1038/nrmicro1341.

17. Barberàn A, Ladua J, Leff JW, Pollard KS, Menninger HL, Dunn RR, Fierer N. 2015. Continental-scale distribution of dust-associated bacteria and fungi. Proc Natl Acad Sci USA 112:5756–5761. http://dx.doi.org/10.1073/pnas.1420815112.

18. Tischer C, Zock JP, Valkonen M, Doekes G, Guerra S, Heederik D, Jarvis D, Norback D, Olivieri M, Suyner J, Swanes C, Täubel M, Thiernig E, Berlato G, Hyvärinen A, Heinrich J. 2015. Predictors of microbial agents in dust and respiratory health in the Ecrhs. BMC Pulm Med 15:48. http://dx.doi.org/10.1186/s12890-015-0042-y.

19. Jacobs J, Borras-Santos A, Krop E, Täubel M, Leppänen H, Haverinen-Shaughnessy U, Pekkanen J, Hyvärinen A, Doekes G, Zock JP, Heederik D. 2014. Dampness, bacterial and fungal components in dust in primary schools and respiratory health in schoolchildren across Europe. Occup Environ Med 71:704–712. http://dx.doi.org/10.1136/medet-2014-102246.

20. Reponen T, Nevalainen A, Jantunen M, Pellikka M, Kallioikoski P. 1992. Normal range criteria for indoor bacteria and fungal spores in a subarctic climate. Indoor Air 2:26–31. http://dx.doi.org/10.1111/j.1600-0668.1992.t01-21.x.