Causal inference between indoor dampness and adverse health effects

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Abstract. Indoor dampness can promote the establishment of microbes in indoor environments, and as such, controlling dampness is important for maintaining a healthy indoor environment. Here, an index is proposed for evaluating indoor dampness based on checking for visible condensation, mold in living rooms and bedrooms, and moldy odors indoors. In this evaluation method, eight items related to visible condensation, presence of mold, and moldy odors are assigned a maximum score of 3 points; the total score (a maximum of 24 points) is then used as an index for the degree of dampness. We classified the total score into four rankings based on quartiles. Rank 4 represents the lowest rank and was assigned to houses that had the most severe levels of indoor dampness. We hypothesized that the lower the rank, the higher the incidence of sick housing syndrome (SHS) would be among young children. To clarify whether there was an association between child SHS and indoor dampness, we conducted an Internet-based cross-sectional survey on children aged 4–12 years. This study first identified potential confounding variables for exposure to indoor dampness using a directed acyclic graph. The results indicated that the higher the degree of dampness, the higher the health risk was for ocular, nasal, and throat symptoms. Dose-response relationships between indoor dampness and SHS were presented using the dampness index proposed in this study.

1 Introduction

In recent years, increased indoor humidity and the establishment of indoor microbes have been promoted by the high airtightness of houses and inappropriate ventilation, leading to concerns about the health effects of microbial contamination. It has been reported that a high humidity indoor environment (humidity) increases the risk of developing allergic diseases, and as such, the impact of the living environment on health has been attracting increasing attention. However, few studies have clarified the cause-and-effect relationship between dampness in the home and health. As shown in Figure 1, the causal relationship between humidity and health is thought to be mediated by indoor environmental contamination. In addition, dryness due to the low humidity environment in winter is known to affect health. Given this background, the present study aimed to clarify the causal relationship between humidity and health effects by constructing a causal model using data obtained from a questionnaire survey.

The authors previously proposed an estimation method for home dampness using occupants' self-reported answers to questions about visible vapor condensation and mold growth during winter. That dampness index ranged from 0 to 24, with values classified into four ranks (Ranks 1 - 4) based on quartiles from the results of a national questionnaire survey of about 5000 houses in Japan. Rank 4 represented the lowest rank and was assigned to houses that had the most severe levels of indoor dampness. We hypothesized that the lower the rank, the higher the incidence of sick housing syndrome (SHS) would be among young children. To clarify whether there was an association between child SHS and indoor dampness, an Internet-based cross-sectional survey was conducted on

Fig. 1. Dampness, health, and the indoor environment.

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children in Japan aged 4 - 12 years during the winter of 2019.

In this paper, potential confounding variables for exposure to indoor dampness were identified using a directed acyclic graph (DAG) to investigate the association between adverse health effects and indoor dampness.

2 Outline of questionnaire survey

2.1 Recruitment of participants

An Internet-based cross-sectional study was conducted on children aged 4–12 years during the winter of 2019. The participants were recruited from among members of a Japanese Internet research company. The houses investigated were detached houses in which the occupants (parents with at least one child aged 4–12 years) had lived for more than 1 year. Questionnaires were distributed online to 5094 houses across 47 prefectures in Japan during the winter season. The occupants answered several questions online for the 5-day investigation period. In this paper, the investigated areas were divided into eight regions according to the Energy Efficiency Standards for Residential Buildings. The total number of respondents was 2579 (Regions 1 and 2: n = 211, Region 3: n = 318, Region 4: n = 434, Region 5: n = 648, Region 6: n = 640, Regions 7 and 8: n = 328), and the overall response rate was 50.6%. The numbers of respondents in Regions 5 and 6 were much higher than those in other regions because these regions include more prefectures and cities with large populations.

<table>
<thead>
<tr>
<th>Personal attributes</th>
<th>Gender, Age, Occupation, School career, Annual income, Number of children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing characteristics</td>
<td>House location, Surrounding environment, Housing type, Floor area, Type of openings, Wall and floor finishing materials, Water damage by leaking (e.g., rain, flooding)</td>
</tr>
<tr>
<td>Heating equipment and ventilation system</td>
<td>Type of heating equipment, Setting temperature of heating equipment, Type of mechanical ventilation system</td>
</tr>
<tr>
<td>Occupant behavior</td>
<td>Operating period of heating equipment and mechanical ventilation system, Operation of air cleaner and dehumidifier, Treatment of vapor condensation and mold growth</td>
</tr>
<tr>
<td>Indoor environment</td>
<td>Evaluation of indoor moisture environment, Visible vapor condensation, Visible mold growth, Damp stain, Perception of moldy odor, Thermal comfort during winter</td>
</tr>
<tr>
<td>Health condition (Respondent)</td>
<td>Diagnosed symptoms and allergic diseases</td>
</tr>
<tr>
<td>Health condition (Child)</td>
<td>Diagnosed symptoms and allergic diseases, Sick house syndrome using Anderson's interview sheet</td>
</tr>
</tbody>
</table>

2.2 Contents of questionnaire

The questionnaire included information on gender, age, housing location, housing type, installed equipment for space heating, type of ventilation system, indoor environmental quality, pattern of operating space heating and mechanical ventilation systems, and performance of the building envelope. Questions about indoor environmental quality addressed the occurrence of visible vapor condensation, visible indoor mold growth, and perception of odors. Questions regarding 13 health-related symptoms among children (e.g., respiratory, skin, ocular, nasal, mental). Respiratory symptoms addressed coughing and shortness of breath, skin symptoms addressed dryness, itch, rash, eczema, and erythema, ocular symptoms addressed redness, dryness, itching, and irritation, and nasal symptoms addressed sneezing, stuffy nose, and runny nose. The responses indicated the onset of every symptom from the indoor environment in the past 3 months. SHS was noted when health outcomes were considered related to the indoor home environment.

2.3 Estimation method of indoor dampness

The authors previously proposed an estimation method for indoor dampness based on the occupants’ self-rated answers to questions about visible vapor condensation, mold growth, the perception of moldy odors, and so on, during the winter season [1]. That dampness index was calculated as a value from 0 to 24 points, which was then classified into four ranks based on quartiles. Rank 4 represented the lowest rank and was assigned to houses that had the most severe levels of indoor dampness. Figure 2 shows the results from a large-scale national survey (N = 5071) conducted in February 2013. The dampness index showed a normal distribution. As the frequency of scores from 0 to 1 was the highest, more scores were allocated to Rank 1. Finally, 37.5% of the houses in total were allocated to Rank 1, 25.0% each to Ranks 2 and 3, and 12.5% to Rank 4.

![Fig. 2. Distribution of dampness index values from the Internet survey conducted in 2013.](image)

2.4 Statistical method

The association between indoor dampness and health-related symptoms among children was estimated using multivariate logistic regression analysis with several confounding factors. Adjusted odds ratios (aORs) were estimated with 95% confidence intervals. The data were analyzed using SPSS (version 26). In this
study, potential confounding variables for exposure to indoor dampness were identified using a DAG (DAGitty version 3.0). A DAG constructed for the dampness index revealed a significant association with SHS.

3 Results from questionnaire survey

3.1 Surveyed house characteristics

Table 2 shows the characteristics and indoor environments in the houses investigated in the questionnaire survey.

In total, health information was available from 4,182 children. The ratio of each age group (3, 4–6, 7–9, and 10–12 years) was about 25%. Approximately half of the children were male. Regarding the ages of the homes, 14.6% were newly constructed within the past 3 years, about 30% were constructed within the past 5–10 years, and about 40% were constructed more than 10 years ago.

The thermal performance of buildings was estimated based on the type of window glass and frame material [2] and classified into four levels according to the energy conservation building code. The 1999 standard had the highest level of thermal performance compared with the 1980, 1992, and 1999 standards. About 44.3% of all homes had a thermal performance with the equivalent of the 1992 standard, whereas < 20% met the 1999 standard.

Vented kerosene heaters were used in 6.0% of all homes and central heating systems in 4.6%. Approximately 23.7% of homes used unvented kerosene or gas heaters, which are traditional sources of home heating in Japan. About 50% of homes used an air conditioning/heating unit during the winter, whereas about 10% used floor heating. The heating equipment was used all the time in 19.3% houses; the majority of homes were being heated intermittently. Moreover, approximately 37.2% of homes used a mechanical ventilation system throughout the winter, and 31.8% intermittently. On the other hand, 30.5% of homes did not use a mechanical ventilation system at all, even though it was equipped according to the Building Standard Law regulations for ventilation.

The occupants perceived moldy odors most frequently in the bathroom (14.7%), followed by the washroom (5.5%), bedroom (4.7%), and living room and child’s room (2.7% in each). In 76.6% of all homes, no moldy odor was perceived.

3.2 Dampness index

Figures 3 shows the surveyed dampness index distribution. The dampness index ranged from 1 to 23 and did not follow a normal distribution, in contrast to a previous large-scale questionnaire survey. About half of the houses were judged to be Rank 1, whereas 13.8% were assigned to Rank 4 (the most severe level of indoor dampness).
4 Causal relationship using DAG

A DAG was used to identify confounding factors in order to evaluate the causal relationship with the “dampness index” as the exposed factor and “SHS” as the outcome. Figure 4 shows the evaluation results. In the DAG, the factors that were considered to be theoretically related on the basis of the researcher’s assessment are listed. The causal structure was derived by connecting the causes and effects with paths. In this paper, we assumed that the “exposed environment” affected the “dampness index”. The “exposed environment” was greatly affected by the heating condition during winter and the operation of mechanical ventilation. In addition, these two factors were considered to be associated with the thermal insulation performance of housing envelopes. “SHS” was associated with “age”, “gender”, and “parents’ health condition”. The “exposed environment” situation was perceived as moldy odor and associated with “SHS”. The confounding factors, which are shown as white ellipses in Figure 4, corresponded to “age”, “gender”, “parents’ health condition”, and “odor”.

5 Results from logistic regression analysis

A logistic regression model was constructed by adjusting for the variables identified by the DAG. The associations between four kinds of health-related symptoms (SHS) among children and indoor dampness (dampness index) are shown in Table 3. The aORs for nasal symptoms (2.76, p < 0.001) was statistically significant (Rank 4 in the dampness index). These results indicated an increased risk of nasal symptoms due to indoor dampness (p for trend < 0.001). Dose-response relationships between indoor dampness and nasal symptoms were identified using the proposed dampness index. In addition, the aORs of ocular and throat symptoms (Rank 4) were statistically significant (1.64, p < 0.05 and 2.01, p < 0.001, respectively). No meaningful associations were found between any other health-related symptoms and indoor dampness. These findings suggest that children living in a damp indoor environment are at a significantly higher risk of developing nasal, ocular, and throat symptoms.

6 Conclusions

The findings of the present study revealed that indoor dampness was associated with allergic symptoms among children; however, the causal mechanisms underlying this association remain unclear. The results of this survey, which aimed to provide a quantitative estimation of indoor dampness using the dampness index proposed by authors, are as follows.

1) The dampness index does not follow a normal distribution, in contrast to a previous large-scale questionnaire survey. In total, 13.8% of the homes surveyed were assigned to Rank 4 (the most severe level of indoor dampness).

2) A DAG identified potential confounding variables for exposure to indoor dampness, including “age”, “gender”, “parents’ health condition”, and “odor”. The authors assumed that the “exposed environment” affected the “dampness index”.

3) The association between adverse health effects (SHS) and influencing factors related to indoor dampness was estimated using a multivariable logistic regression model. The results revealed that children living in a damp indoor environment are at a significantly higher risk of developing nasal, ocular, and throat symptoms. Moreover, dose-response relationships between indoor dampness and nasal symptoms were identified using the dampness index proposed by the authors.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Frequency</th>
<th>Ocular symptoms (n = 220)</th>
<th>Nasal symptoms (n = 670)</th>
<th>Throat symptoms (n = 449)</th>
<th>Skin symptoms (n = 327)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>aOR^2 (95%CI)</td>
<td>aOR^2 (95%CI)</td>
<td>aOR^2 (95%CI)</td>
<td>aOR^2 (95%CI)</td>
</tr>
<tr>
<td>Dampness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank 1</td>
<td>2,233</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Rank 2</td>
<td>916</td>
<td>0.99 (0.68–0.45)</td>
<td>1.57 *** (1.26–1.96)</td>
<td>1.03 (0.81–1.38)</td>
<td>1.11 (0.83–1.50)</td>
</tr>
<tr>
<td>Rank 3</td>
<td>546</td>
<td>1.15 (0.75–1.75)</td>
<td>1.64 *** (1.27–2.13)</td>
<td>1.26 (0.93–1.70)</td>
<td>1.02 (0.72–1.46)</td>
</tr>
<tr>
<td>Rank 4</td>
<td>487</td>
<td>1.64 * (1.11–2.43)</td>
<td>2.76 *** (2.14–3.56)</td>
<td>2.01 *** (1.50–2.69)</td>
<td>1.18 (0.83–1.68)</td>
</tr>
<tr>
<td>p for trend</td>
<td></td>
<td>p=0.078</td>
<td>p&lt;0.001</td>
<td>p=0.018</td>
<td>p=0.768</td>
</tr>
</tbody>
</table>

^ Adjusted for age, gender, parents’ health condition related to allergies and perception of moldy odor.

CI = confidence interval; * p<0.05  ** p<0.01  *** p<0.001
Acknowledgement

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References


