Indoor environment and adverse health symptoms among children under home damp conditions

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ABSTRACT

Building dampness and mouldy indoor environments are associated with the increase of approximately 30-50% in variety of respiratory and asthma-related health outcomes through a meta-analysis. The indoor environment related to indoor dampness is not be revealed yet, however it is important to provide the architectural techniques and optimal occupant behavior for prevention of dampness in buildings. The authors previously proposed an estimation method for home dampness using occupants self-reported answers to questions about visible vapor condensation, visible mould growth during winter. This dampness index ranges from 0 to 24, and its values were classified into four ranks (Rank 1 to Rank 4) based on quartiles from the results of a national questionnaire survey of about 5,000 houses in Japan. In order to clarify the association between home dampness and indoor environmental quality, questionnaire survey was conducted and several physical environmental items such as indoor temperature, humidity and microbial flora from the floor dust were measured in 120 detached houses located in East Japan.
This paper firstly describes the quantitative estimation of indoor dampness through the dampness index and the surveyed results from measured houses. The questionnaires also included items regarding the following health-related symptoms onset within 3 months among children. The dampness index is not following to normal distribution like a previous large scale questionnaire survey. And the prevalence of nasal symptoms (chi-square test: $p < 0.01$) and ocular symptoms increased as rank of dampness index was rising.
Secondary, the characteristics of indoor temperature, humidity and microbial flora due to home dampness were clarified by comparing dampness index and measured results of these physical items. The microorganisms were genetically analysed to evaluate the population diversity of microbial species through the DNA analysed technologies. The median relative humidity in each dampness rank was higher at higher rank of indoor dampness. This tendency was statistically significant for both a living room and a bed room, and humidity ratio at rank 1 was significantly lower than that at rank 3 and rank 4. The fungal species of which the detection rate was increasing with ranks 1 to 4 of indoor dampness index were considered to be associated with indoor environmental problems of dampness. This paper indicates the association between indoor dampness and fungal species of *Wallemia sebi* and *Rhodotorula glutinis*.
Finally, the association between adverse health effect and influencing factors related to indoor dampness was estimated using a multivariable logistic regression model. As results, it was revealed that children who were living in dampness are at significant risk for health-related symptoms such as nasal symptoms and dermal symptoms.

KEYWORDS

Home dampness, Health-related symptoms, Indoor temperature and humidity, Microorganism flora

1 INTRODUCTION

Building dampness and mouldy indoor environments are associated with the increase of approximately 30-50% in variety of respiratory and asthma-related health outcomes through a meta-analysis. The indoor environment related to indoor dampness is not be revealed yet, however it is important to provide the architectural techniques and optimal occupant behavior for prevention of dampness in buildings. The causal structure from dampness to adverse health effect seems to be estimated as shown in Figure 1. Based on these causalities it is expected to reveal prevention methodologies for serious problems related to indoor dampness. The authors previously proposed an estimation method for home dampness using occupants self-reported answers to questions about visible vapor condensation, visible mould growth during winter. This dampness index ranges from 0 to 24, and its values were classified into four ranks (Rank 1 to Rank 4) based on quartiles from the results of a national questionnaire survey of about 5,000 houses in Japan. The houses in the Rank 4 represents the most serious problems related to indoor dampness. In addition, it is expected to reveal the actual condition of indoor dampness. In order to clarify the association between home dampness and indoor environmental quality, questionnaire survey was conducted and several physical environmental items such as indoor temperature, humidity and microbial flora from the floor dust were measured in 120 detached houses located in East Japan during winter.

This paper firstly describes the quantitative estimation of indoor dampness through the dampness index proposed by authors and the surveyed results from measured houses. The questionnaires also included items regarding the following health-related symptoms onset within 3 months among children: ocular symptoms, nasal symptoms, respiratory symptoms, dermal symptoms and mental symptoms. The prevalence of these symptoms was presented in each dampness index rank.

Secondary, the characteristics of indoor temperature, humidity and microbial flora due to home dampness were clarified by comparing dampness index and measured results of these physical items. The microorganisms were genetically analysed to evaluate the population diversity of microbial species based on the length of ITS. In this paper, fungal diversity included in the floor dust of surveyed 120 houses was analysed and then these samples were also performed comprehensive analysis using the next generation sequencer.

Finally, the association between indoor dampness and health-related symptoms among young children was presented by statistical analysis method.

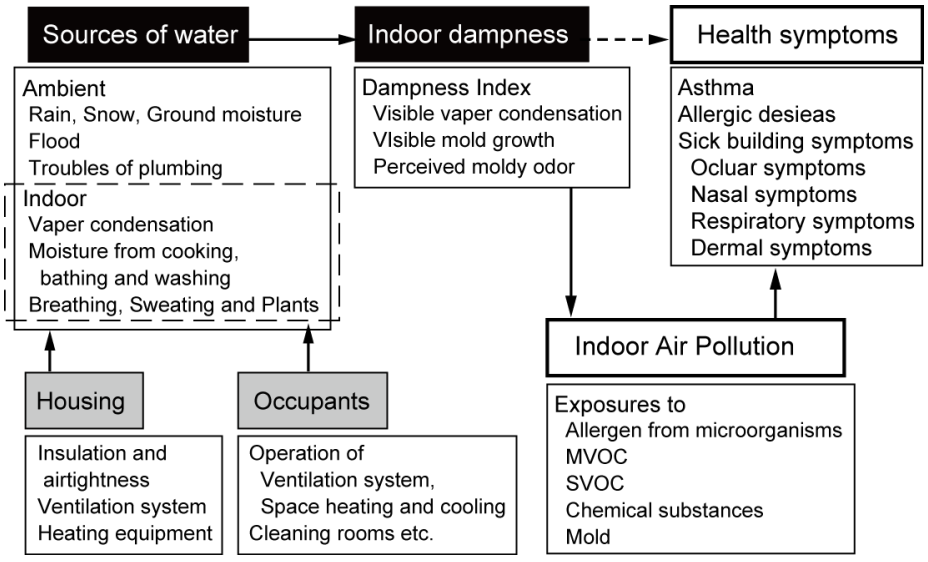

Figure 1: Dampness, indoor environment and health

2 METHODOLOGIES OF SURVEY

2.1 Outline of survey

A cross-sectional study has been conducted to 6 - 12 years old children through the internet survey in the winter of 2017. The subjects to meet the requirements for respondent were recruited from the customers which a Japanese internet research company held. The investigated houses were detached houses which occupants had lived for more than one year and had parents and more one child who was 6 -12 years old. Questionnaires were distributed on the web to the 120 houses in Japan during winter season, and continuously the indoor temperature, humidity and microorganisms in sampling dust were measured in five days. The occupants answered several questions on the internet web site for five days of the investigation period and measured indoor temperature and humidity in a living room and bed room using small thermo-hygrometer. In addition, the occupants were asked to collect floor dust in a living room and bed room with a vacuum cleaner. The investigated areas were belonging to the northern portion of Japan, which were snowy and cold regions.
The questionnaire included information regarding 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, the performance of the building envelope, and others. Questions about indoor environmental quality addressed the occurrence of visible vapour condensation, visible mould growth indoors and perception of odours. Questions regarding thirteen health-related symptoms among children, which reflected respiratory symptoms, dermal symptoms, ocular symptoms, nasal symptoms and mental symptoms. Respiratory symptoms addressed cough and shortness of breath, dermal symptoms dryness, itch, rash, eczema and erythema, ocular symptoms addressed redness, dryness, itch and irritation and nasal symptoms addressed sneezing, stuffy and runny nose. Answers indicated every symptom onset from indoor environment in three months.
The microorganisms were genetically analysed to evaluate the population diversity of microbial species based on the length of ITS. The fungal DNA of each house was obtained from the floor dust of 50mg which was collected in a living room and bed room using a vacuum cleaner. The ITS regions are located among the ribosomal RNA genes that are a part of genome of microorganisms, and is hyper-variable, suggesting its length is a unique signature in each microorganism. In this paper we analysed spacers ITS2 using the fungal-specific primers ITS3 and ITS4. Fungal diversity included in the floor dust of surveyed 120 houses was analysed and then these samples were also performed comprehensive analysis using the next generation sequencer. All base sequence data sets were clustered using more than 97% sequence similarity and the fungal species were identified with UNITE database v7.2.

2.2 Evaluation method of indoor dampness

Authors have already proposed the estimation method of indoor dampness using the results of occupants self-rated answers to questions about visible vapor condensation, mould growth, perception of mouldy odor and so on during winter season (Hasegawa, 2016). This dampness index was calculated as the value from 0 to 24 points and its values classified into four kinds of rank on the basis of the quartile. Rank 4 presented the house which had the most serious problems related to dampness. Figure 2 presents the results from large scale national survey (N=3,765, conducted on February of 2014). A distribution of dampness index from this survey approximately has a normal distribution. In addition the dampness index revealed an association between indoor dampness and health-related symptoms among children.

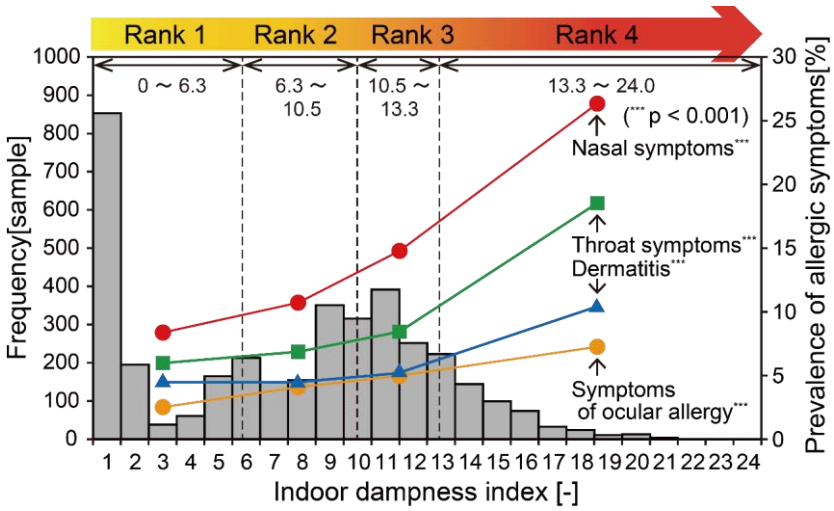

Figure 2: Distribution of dampness index and prevalence of allergic symptoms from the last survey

3 INDOOR ENVIRONMENT OF DAMPNESS IN HOUSES

3.1 Indoor dampness index

Figures 3 present surveyed dampness index distribution and the prevalence of health-related symptoms among children for each rank from 119 houses. The dampness index ranged from 1 to 22 and it is not following to normal distribution like a previous large scale questionnaire survey. The prevalence of nasal symptoms (chi-square test: $p < 0.01$) and ocular symptoms increased as rank of dampness index was rising. In particular the prevalence of nasal symptom in Rank 4 was more 50% among children. The prevalence of throat symptoms and dermatitis was the biggest in Rank 3, and there is no clear association between dampness index and health-related symptoms.

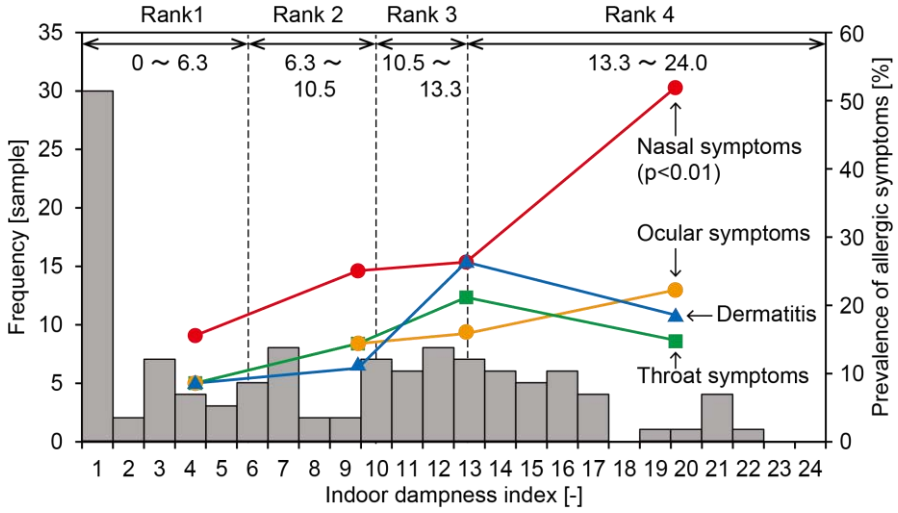

Figure 3: Distribution of dampness index and prevalence of allergic symptoms

3.2 Indoor temperature and humidity

Figures 4 to 6 present the statistical values of temperature, relative humidity and humidity ratio during staying in a living room and bed room for each rank of indoor dampness. The values in every rank of indoor dampness index include the median, the first and third quartiles, and the

maximum and minimum values of temperature and humidity during measuring periods from 119 houses. In order to test the significance of these associations, Kruskal-Wallis test, which is one of non-parametric method, was performed to evaluate whether samples in each rank of indoor dampness index originate from the same distribution. Moreover, the significant difference among samples of each rank was tested by multiple comparison.

As for the result of temperatures in Figure 4, no significant association was found among each rank of indoor dampness index. This tendency is presumed that the temperature in a living room was affected by the heating behaviour at the time of occupancy. Although an association between the temperature in a bedroom and dampness index was not statistically significant, p value (p=0.084) in a bed room was lower than that in a living room and the temperature tended to be decreasing for Rank 4.

On the other hand, the relative humidity and the humidity ratio associated significantly rank of indoor dampness index though the Kruskal-Wallis test as shown in Figure 5 and 6. It was indicated that the higher the rank of indoor dampness index, the higher the humidity in a living room and bed room. In addition, the relative humidity and humidity ratio in a living room at Rank 2, 3 and 4 were significantly increasing in comparison with at Rank 1. As the humidity ratio at Rank 4 was found to be significantly the highest among surveyed houses, it was expected that these houses at Rank 4 had severe environmental problems for indoor dampness. There was the significant difference between humidity ratio in a bed room among each rank, and the humidity ratio at rank 4 was not the highest.

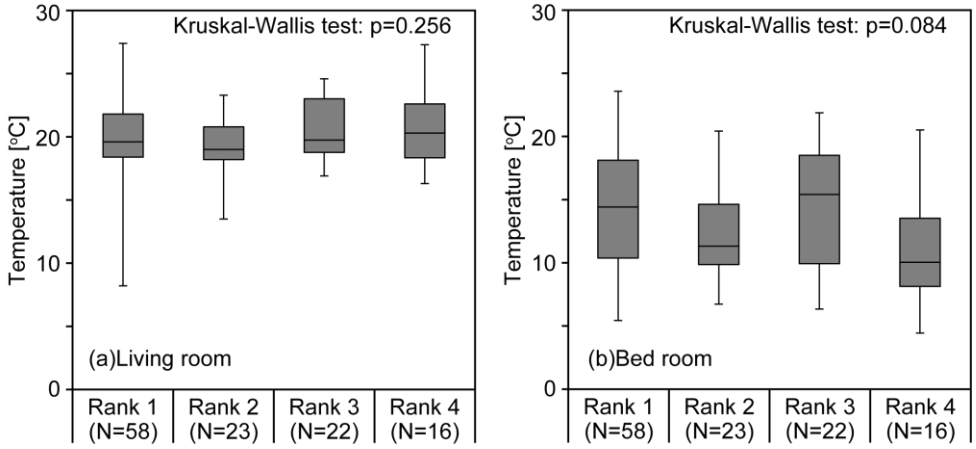

Figure 4: Dampness rank and temperature in a living room and bedroom

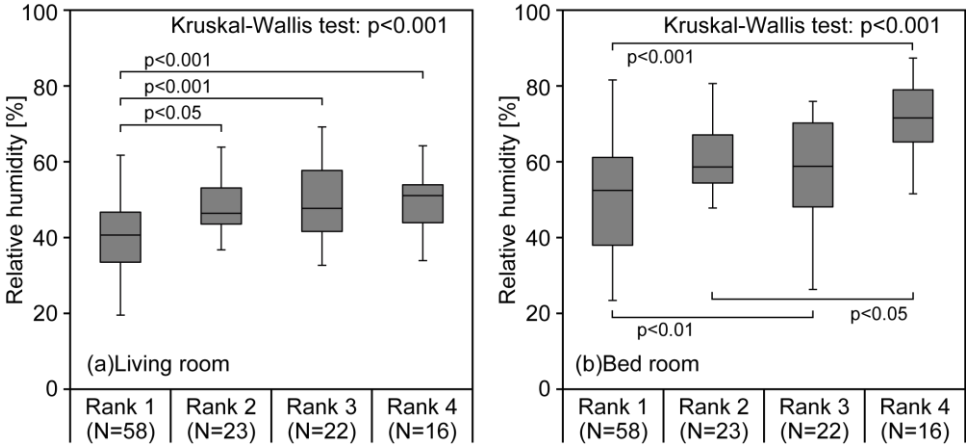

Figure 5: Dampness rank and relative humidity in a living room and bedroom

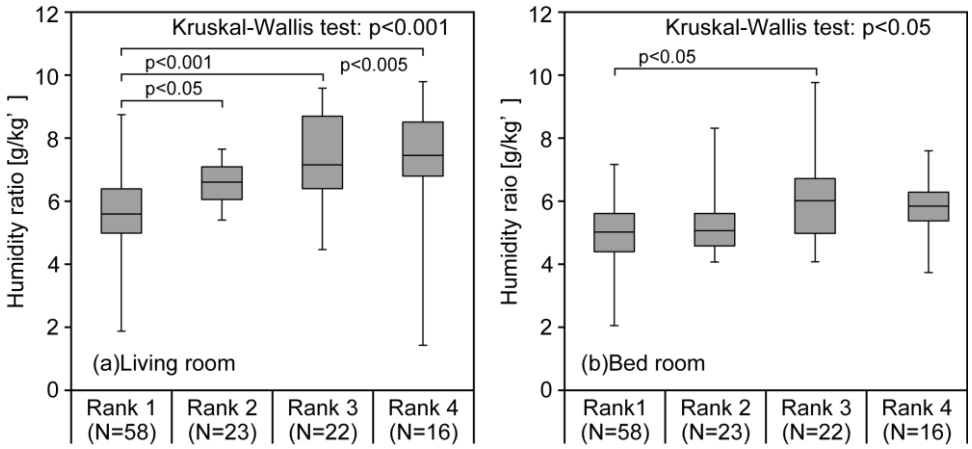

Figure 6: Dampness rank and humidity ratio in a living room and bedroom

3.3 Microorganisms flora

In the surveyed houses though DNA analysis method, 1,522 kinds of fungal species were detected. Table 1 presented the detection ratio of several fungal species at ranks of indoor dampness index.

Table 1: The detection ratio of microbial species

Fungal species	Rank of dampness index				Fungal species	Rank of dampness index				Fungal species	Rank of dampness index			
	1	2	3	4		1	2	3	4		1	2	3	4
Aspergillu sappendiculatus	96.4	95.5	93.8	100.0	*Graphiolaphoenicis*	54.5	63.6	87.5	71.4	*Trametes versicolor*	40.0	63.6	37.5	52.4
Aspergillus conicus	98.2	100.0	93.8	100.0	*Hortaea werneckii*	52.7	68.2	62.5	71.4	*Yamadazyma triangularis*	30.9	22.7	18.8	52.4
Aspergillus penicillioides	100.0	100.0	100.0	100.0	*Mycosphaerella tassiana*	58.2	81.8	68.8	71.4	*Aspergillus hongkongensis*	25.5	50.0	25.0	47.6
Cladosporium sphaerospermum	94.5	100.0	100.0	100.0	*Trichosporon insectorum*	61.8	77.3	75.0	71.4	*Candida zeylanoides*	52.7	54.5	68.8	47.6
Mycosphaerella punctiformis	96.4	95.5	93.8	100.0	*Aureobasidium pullulans*	76.4	72.7	62.5	66.7	*Exophiala cancerae*	60.0	90.9	81.3	47.6
Penicillium jiangxiense	96.4	90.9	81.3	100.0	*Hypsizygus marmoreus*	50.9	77.3	43.8	66.7	*Gibellulopsis nigrescens*	29.1	59.1	37.5	47.6
Penicillium kongii	94.5	90.9	100.0	100.0	*Knufia epidermidis*	52.7	63.6	81.3	66.7	*Grifola frondosa*	49.1	50.0	68.8	47.6
Toxicocladosporium rubrigenum	94.5	100.0	100.0	100.0	*Penicillium decumbens*	34.5	59.1	56.3	66.7	*Lentinula edodes*	56.4	63.6	68.8	47.6
Verrucocladosporium dirinae	100.0	100.0	100.0	100.0	*Penicillium digitatum*	50.9	77.3	62.5	66.7	*Panellus serotinus*	40.0	27.3	43.8	47.6
Alternaria betae-kenyensis	100.0	95.5	100.0	95.2	*Phlebia radiata*	63.6	59.1	75.0	66.7	*Paraphaeosphaeria sardoa*	41.8	59.1	43.8	47.6
Aspergillus parasiticus	87.3	95.5	100.0	95.2	*Talaromyces veerkampii*	60.0	59.1	43.8	66.7	*Pestalotiopsis trachicarpicola*	36.4	18.2	31.3	47.6
Cyphellophora europaea	94.5	95.5	100.0	95.2	*Arthrocatena tenebrio*	45.5	77.3	62.5	61.9	*Pholiota microspora*	45.5	40.9	37.5	47.6
Rhodotorula mucilaginosa	96.4	95.5	93.8	95.2	*Cutaneotrichosporon jirovecii*	36.4	63.6	37.5	61.9	*Sagenomella griseoviridis*	21.8	31.8	56.3	47.6
Schizopora ovispora	74.5	77.3	68.8	95.2	*Fusarium oxysporum*	54.5	68.2	68.8	61.9	*Sistotrema sernanderi*	30.9	63.6	25.0	47.6
Filobasidium magnum	94.5	86.4	87.5	90.5	*Gibberella tricincta*	61.8	59.1	68.8	61.9	*Vishniacozyma carnescens*	38.2	54.5	37.5	47.6
Penicillium armarii	83.6	77.3	87.5	90.5	*Guehomyces pullulans*	45.5	68.2	56.3	61.9	*Acremonium charticola*	21.8	31.8	37.5	42.9
Sphaerulina rhabdoclinis	83.6	90.9	93.8	90.5	*Metschnikowia reukaufii*	60.0	50.0	68.8	61.9	*Aureobasidium subglaciale*	32.7	54.5	31.3	42.9
Sterigmatomyces halophilus	54.5	72.7	75.0	90.5	*Neoascochyta desmazieri*	78.2	63.6	68.8	61.9	*Calycina marina*	36.4	36.4	37.5	42.9
Wallemia mellicola	54.5	81.8	81.3	90.5	*Penicillium onobense*	45.5	50.0	43.8	61.9	*Camptophora hylomeconis*	45.5	54.5	50.0	42.9
Wallemia sebi	43.6	77.3	75.0	90.5	*Plectosphaerella alismatis*	74.5	81.8	75.0	61.9	*Candida parapsilosis*	56.4	31.8	56.3	42.9
Penicillium ornatum	74.5	86.4	81.3	85.7	*Clavispora lusitaniae*	63.6	68.2	87.5	57.1	*Cladosporium halotolerans*	56.4	31.8	56.3	42.9
Pyrenochaeta keratinophila	70.9	68.2	68.8	85.7	*Didymella aurea*	43.6	68.2	43.8	57.1	*Cryptococcus uniguttulatus*	25.5	36.4	37.5	42.9
Wallemia tropicalis	60.0	77.3	68.8	85.7	*Exophiala equina*	45.5	59.1	68.8	57.1	*Cutaneotrichosporon curvatus*	23.6	45.5	31.3	42.9
Capnobotryella renispora	69.1	77.3	75.0	81.0	*Hannaella oryzae*	56.4	68.2	75.0	57.1	*Exophiala xenobiotica*	29.1	45.5	31.3	42.9
Neocatenulostroma abietis	74.5	77.3	81.3	81.0	*Malassezia restricta*	67.3	63.6	56.3	57.1	*Flammulina velutipes*	54.5	45.5	43.8	42.9
Penicillium corylophilum	76.4	77.3	62.5	81.0	*Malassezia sympodialis*	50.9	31.8	62.5	57.1	*Kondoa aeria*	29.1	31.8	37.5	42.9
Rhodotorula glutinis	67.3	81.8	75.0	81.0	*Neodevriesia imbrexigena*	47.3	59.1	50.0	57.1	*Magnusiomyces capitatus*	38.2	13.6	37.5	42.9
Saccharomyces cariocanus	89.1	95.5	87.5	81.0	*Ochroconis mirabilis*	47.3	54.5	62.5	57.1	*Mycosphaerella handelii*	49.1	31.8	56.3	42.9
Alternaria infectoria	69.1	63.6	62.5	76.2	*Penicillium roqueforti*	40.0	63.6	31.3	57.1	*Penicillium citrinum*	27.3	45.5	25.0	42.9
Aspergillus restrictus	60.0	77.3	68.8	76.2	*Aspergillus conversis*	41.8	63.6	43.8	52.4	*Phyllotopsis nidulans*	30.9	27.3	50.0	42.9
Fusarium asiaticum	74.5	77.3	62.5	76.2	*Candida albicans*	36.4	45.5	31.3	52.4	*Schizopora flavipora*	34.5	31.8	43.8	42.9
Pseudotaeniolina globosa	65.5	54.5	62.5	76.2	*Candida etchellsii*	27.3	36.4	12.5	52.4	*Sistotremastrum guttuliferum*	41.8	36.4	43.8	42.9
Sporobolomyces phaffii	70.9	54.5	75.0	76.2	*Candida magnoliae*	32.7	31.8	31.3	52.4	*Symmetrospora foliicola*	52.7	54.5	56.3	42.9
Stemphylium herbarum	70.9	81.8	87.5	76.2	*Candida parapsilosis*	40.0	68.2	37.5	52.4	*Trametes hirsuta*	40.0	31.8	37.5	42.9
Trichosporon debeurmannianum	54.5	86.4	81.3	76.2	*Cystobasidium lysinophilum*	38.2	63.6	43.8	52.4	*Vermiconia calcicola*	41.8	31.8	25.0	42.9
Aspergillus niger	85.5	72.7	100.0	71.4	*Malassezia dermatis*	45.5	31.8	56.3	52.4	*Vishniacozyma victoriae*	54.5	31.8	56.3	42.9
Aureobasidium melanogenum	56.4	77.3	68.8	71.4	*Malassezia globosa*	56.4	68.2	50.0	52.4	*Xerochrysium dermatitidis*	38.2	40.9	37.5	42.9
Bjerkandera adusta	69.1	59.1	75.0	71.4	*Meyerozyma guilliermondii*	30.9	50.0	31.3	52.4	*Yarrowia lipolytica*	63.6	68.2	62.5	42.9
Cystofilobasidium macerans	54.5	77.3	62.5	71.4	*Neofabraea vagabunda*	54.5	54.5	31.3	52.4	*Apiotrichum montevideense*	30.9	59.1	31.3	38.1
Debaryomyces hansenii	47.3	77.3	68.8	71.4	*Papiliotrema flavescens*	47.3	36.4	56.3	52.4	*Ascosphaera atra*	14.5	31.8	25.0	38.1

The fungal species of which the detection rate was increasing with ranks 1 to 4 of indoor dampness index were considered to be associated with indoor environmental problems of dampness. For example, this trend was found on fungal species of *Wallemia sebi* and

Rhodotorula glutinis. Also, the association between the OTU ratio of fungal species in each house and the rank of indoor dampness index was statistically analysed though Kruskal-Wallis test. As results, it was estimated that the higher the rank of indoor dampness index, the higher the detection ratio such as *Aspergillus* spp., *Trichosporon* spp., *Wallemia mellicola*, and *Wallemia sebi*. If the major fungal species related to indoor dampness in houses of Japan were clarified from the population diversity of microbial species, we could understand the indoor microbial contamination related to indoor dampness.

4 ADVERSE HEALTH EFFECT AND DAMPNESS INDEX

4.1 Outline of statistical analysis

The associations between indoor dampness and health-related symptoms among children were estimated using a multivariate logistic regression analysis with adjustment for gender, age and parents health condition. Adjusted odds ratios were estimated including the 95% confidence interval (CI). We analysed the data using the Statistical Package for the Social Sciences (SPSS version 23).

4.2 Analysed results

Associations between four kinds of health-related symptoms among children and indoor dampness are presented in Table 2. Adjusted ORs of nasal symptoms (AOR = 5.25, $p < 0.01$) was statistically significant in rank 4 of the dampness index. In this analysed results, the increased risk of nasal symptoms due to indoor dampness was estimated (p for trend <0.05). The dose-response relationships between indoor dampness and nasal symptoms was presented using the dampness index proposed by authors. In addition, adjusted ORs of dermal symptoms in rank 3 of dampness index (AOR = 4.26, $p < 0.05$) was statistically significant. There were not meaningful associations for other health-related symptoms with indoor dampness. In this paper, we could conclude that children who were living in dampness are at significant risk for health-related symptoms such as nasal symptoms and dermal symptoms.

Table 2: AORs for ocular symptoms, nasal symptoms, throat symptoms and dermal symptoms

Factors	Frequency	Adjusted OR[a] (95%CI)			
		Ocular symptoms	Nasal symptoms	throat symptoms	Dermal symptoms
Rank of dampness Index					
Rank 1	71	1.00 (*Ref.*)	1.00 *(Ref.)*	1.00 *(Ref.)*	1.00 *(Ref.)*
Rank 2	28	2.03 (0.51-8.14)	1.42 (0.47-4.28)	1.57 (0.39-6.29)	1.51 (0.32-7.20)
Rank 3	19	1.92 (0.43-8.66)	2.16 (0.62-7.59)	2.82 (0.68-11.7)	4.26* (1.02-17.7)
Rank 4	27	3.39† (0.96-12.0)	5.25** (1.88-14.7)	1.69 (0.26-2.00)	3.23 (0.82-12.7)
p for trend		0.302	<0.05	0.544	0.166

[a] Adjusted for age, gender and parents health condition related to allergies.
CI = confidence interval; †<0.1, *<0.05, **<0.01

5 CONCLUSIONS

The indoor dampness was associated with allergic symptoms among children, however the causal mechanisms was not be revealed yet. This paper describes the quantitative estimation of indoor dampness using dampness index proposed by authors and measured results such as indoor temperature, humidity and microorganisms. The microorganisms were genetically analysed to evaluate the population diversity of microbial species through the DNA analysed technologies. The results from this survey are shown as follows.

1) The dampness index is not following to normal distribution like a previous large scale questionnaire survey. The characteristics of indoor temperature, humidity and microbial flora due to home dampness were clarified by comparing dampness index and measured results of these physical items. The median relative humidity in each dampness rank was higher at higher rank of indoor dampness. This tendency was statistically significant for both a living room and a bed room, and humidity ratio at rank 1 was significantly lower than that at rank 3 and rank 4.
2) The fungal species of which the detection rate was increasing with ranks 1 to 4 of indoor dampness index were considered to be associated with indoor environmental problems of dampness. This paper indicates the association between indoor dampness and fungal species of *Wallemia sebi* and *Rhodotorula glutinis*.
3) The association between adverse health effect and influencing factors related to indoor dampness was estimated using a multivariable logistic regression model. As results, it was revealed that children who were living in dampness are at significant risk for health-related symptoms such as nasal symptoms and dermal symptoms.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Fisk WJ, Lei-Gomez Q, Mendell MJ. (2007). Meta-analyses of the associations of respiratory health effects with dampness and mold in homes. *Indoor Air '07*, 17(2):84-96.

Hasegawa K et al, 2016. National survey on home dampness and children's allergic symptoms during consecutive survey periods in Japan, *Proceedings of Indoor Air 2016*, ID400:1-2.