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Indoor fungal levels in temporary houses occupied following the Great East Japan Earthquake of 2011

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ABSTRACT

After the Great East Japan Earthquake of 2011 and subsequent tsunami, several tens of thousands of residents in the area of Tohoku, Japan were evacuated to temporary houses, some of which featured inappropriate thermal conditions. In this study, indoor airborne and settled fungal levels were determined in living rooms and bedrooms following the occupation of 34 temporary houses in Minamisoma City (Fukushima, Japan). Average indoor levels of airborne fungi were 1200 ± 970, 1700 ± 1,000, and 2100 ± 2700 CFU/m^3 in the winter and summer of 2012, and summer of 2014, respectively. In 47%, 71%, and 63% of temporary houses, airborne fungal levels exceeded AIJ standard levels (1000 CFU/m^3) in the winter and summer of 2012 and summer of 2014, respectively. Aspergillus spp., Cladosporium spp., and Penicillium spp. were the dominant species in these temporary houses, similar to those previously observed in typical Japanese houses. Airborne fungal levels significantly correlated with the proportion of time when relative humidity was > 70% in the summer of 2012, while no correlation was observed in the winter. Indoor-outdoor (I/O) ratios of airborne fungal levels were higher in winter than in summer. Airborne fungal levels were lower in wooden temporary houses than in other types of temporary houses, likely because of humidity difference. For most fungi, airborne levels did not correlate with levels in settled dust.

Practical implications

Indoor airborne and settled fungal levels were determined in temporary houses occupied by earthquake and tsunami evacuees in Minamisoma City, Fukushima, Japan. *Aspergillus*, *Cladosporium*, and *Penicillium* spp. were the dominant fungal species present, as reported in studies of standard housing conducted in Japan and around the world. However, levels in the temporary houses studied were significantly higher than those in typical Japanese houses, likely due to differences in insulation and ventilation, and consequently in humidity. Airborne fungi levels were significantly correlated with the percentage of time during which relative humidity was greater than 70%. Airborne fungal levels were lower in wooden temporary houses than in other types of houses, likely due to differences in humidity; these findings may help inform the construction of temporary housing in the future.

1. Introduction

On March 11, 2011, the Great East Japan Earthquake and a subsequent tsunami devastated the northeastern coast of Japan, damaging the Fukushima Daiichi nuclear power plant. On March 12, 2011, 77,000 residents were evacuated from ten towns and villages within 20 km of the power plant, and people living within 20–30 km of the site were urged to stay indoors because of a hydrogen explosion at the plant [1]. People who lost their homes due to the earthquake and tsunami, or who lived within a 20-km radius of the plant, have been housed in more than 54,000 temporary houses, constructed mainly in three prefectures (Fukushima, 18,000; Miyagi, 22,000; and Iwate, 14,000) [2]. Until February 2013, temporary houses in Fukushima prefecture were built in an area more than 20 km away from the power plant, such as in Minamisoma City, and some residents have been living in temporary houses for more than 5 years. Minamisoma City (Fukushima, Japan) is located in a cold region of Japan and has a marine climate [average temperatures of 2.0 °C in the winter (January and February) and 23.0 °C in the summer (July and August), from the years 1981–2010] [3,4].

Japanese climate, high temperature and humidity, is suitable for fungal growth. The average indoor airborne fungal levels of typical

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Table 1
Fungal indoor-outdoor (I/O) ratios in temporary houses.

		Cladosporium sp.	*Aspergillus* sp.	*Penicillium* sp.	Yeast	*Aspergillus niger*	*Rhizopus* sp.	Mycelia	*Alternaria* sp.	*Fusarium* sp.	*Wallemia sebi*	*Eurotium* sp.	Actinomycete	TOTAL
2012 Winter	AM ± SD	20 ± 38	40 ± 65	31 ± 67	21 ± 59	14 ± 38	–	1.0 ± 0.18	–	–	3.3 ± 4.0	7.5 ± 18	13 ± 31	9.8 ± 9.5
	Median	4.5	21	8.0	1.0	1.0	–	1.0	–	–	1.5	1.0	1.0	6.6
	25th–75th percentile	0.61–12	1.7–46	3.5–20.5	0.50–4.75	1.0–1.0	–	1.0–1.0	–	–	1.0–4.0	1.0–4.0	0.28–1.0	2.7–15
	Percentage of I/O > 1	70%	97%	92%	53%	–	–	–	–	–	77%	43%	63%	95%
2012 Summer	AM ± SD	0.75 ± 0.66	19 ± 25	1.8 ± 1.6	2.6 ± 8.9	1.0 ± 0.18	–	1.1 ± 1.1	1.5 ± 1.8	–	32 ± 47	7.0 ± 10	5.2 ± 13	2.0 ± 1.4
	Median	0.50	9.8	1.2	0.75	1.0	–	1.0	0.75	–	17	2.0	1.0	1.8
	25th–75th percentile	0.33–1.1	4.3–21	0.48–2.7	0.29–1.4	1.0–1.0	–	1.0–1.0	0.50–1.3	–	5.5–41	1.0–8.5	0.50–2.0	1.0–2.3
	Percentage of I/O > 1	26%	88%	61%	40%	–	–	–	53%	–	97%	70%	60%	76%
2014 Summer	AM ± SD	1.0 ± 0.57	18 ± 27	23 ± 79	1.3 ± 1.2	1.5 ± 1.4	0.84 ± 0.47	3.0 ± 4.2	0.97 ± 1.5	2.2 ± 4.3	6.3 ± 7.0	2.7 ± 6.7	–	3.2 ± 3.2
	Median	1.0	9.1	1.4	0.93	1.0	1.0	0.73	1.0	1.0	3.0	1.0	–	1.8
	25th–75th percentile	0.71–1.3	1.9–36	0.57–4.5	0.41–2.0	1.0–2.0	1.0–1.0	0.20–1.7	0.30–1.0	0.40–1.0	1.0–9.5	1.0–1.0	–	1.1–3.8
	Percentage of I/O > 1	45%	92%	62%	49%	81%	78%	46%	57%	51%	97%	95%	–	82%

Japanese houses, assessed using DG18 cultures, are < 13–3750 CFU/m^3 [a geometric mean (GM): 138 CFU/m^3][5] and 0–3370 CFU/m^3 (GM: 248 CFU/m^3) [6]. Fungal toxicity has been reported due to emitted mycotoxins and various allergens. Mycotoxins, which have high thermal tolerance, are produced by *Aspergillus* spp., *Fusarium* sp., and *Penicillium* spp [7]. Allergies and asthma have also been reported to be associated with indoor fungi, including *Aspergillus* spp., *Cladosporium* spp., and *Penicillium* spp [8–11].

Residents often used combustion heaters in the narrow temporary houses because of the cold climate, likely leading to increasing indoor humidity during the winter. In the summer, indoor temperatures and humidity are high, similar to the external conditions. This environment facilitates fungal growth as relative humidity (RH) and temperature are recognized factors that enhance the growth of molds [12–16].

They are also significantly higher in living rooms with areas of < 10 m^2 compared to those with areas of > 10 m^2, and on ground floors than in upper levels [17]. In addition, fungal counts are significantly higher in wooden board houses and iron-framed prefabricated houses than in reinforced concrete houses [18]. Every temporary house was built on ground floor using wooden, ceramic, or steel panel and the rooms are mostly < 10 m^2. Based on these studies, fungal levels in the temporary houses urgently constructed for the natural disaster evacuees were predicted to be high. Moreover, the indoor fungal levels could be varied among types of temporary houses.

In the current study, the following survey and measurements were conducted in 19, 17, and 27 temporary houses during their occupation in the winter and summer of 2012, and the summer of 2014, respectively, to evaluate the fungal levels and thermal conditions in their indoor environments. Factors assessed included (i) the levels of airborne and settled fungi, determined empirically; (ii) temperature and humidity, determined empirically; (iii) humidity and dew condensation determined via a questionnaire-based survey.

2. Materials and methods

2.1. Survey area, period, and characteristics of temporary houses

The survey was conducted in Minamisoma City, located in the coastal area of Fukushima prefecture. Approximately one-third of Minamisoma City is within 20 km of the Fukushima Daiichi nuclear power plant. The temporary houses in Minamisoma City were constructed and occupied more than 30 km away from the power plant during 2011. In the present study, 34 temporary houses in 22 temporary housing developments built by different companies in different time periods, were selected. Each temporary housing development, 18–379 housing units of the same size and structure.

Indoor airborne and settled fungal levels were determined during occupation in the winter (n = 19) and summer (n = 17) of 2012 and in the summer (n = 27) of 2014. Measurements were conducted three times in 10 houses (winter and summer 2012 and summer 2014), twice in 9 houses (6 houses in winter and summer 2012; 2 houses in winter 2012 and summer 2014; 1 house in summers 2012 and 2014), and once in 15 houses (1 house in winter 2012 and 14 houses in summer 2014). The temporary houses were categorized as prefabricated houses with steel plate walls (type 1), prefabricated houses with ceramic panel walls (type 2), and wooden log houses (type 3). An air conditioner for heating and cooling was installed in the living room or bedroom in each temporary house, whereas installation of additional heating and cooling instruments was at the discretion of the occupants. Ventilation fans were installed in three locations in every house: the kitchen, bathroom, and restroom. Three houses (E, L, and R) were occupied at the time of the 2012 survey; however, the residents had left and the houses were vacant at the time of the 2014 survey.