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Moldy odor from air conditioners in the residences of Japanese participants with and without asthma

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Abstract

Fungi, a major allergen associated with asthma onset and severity, can contaminate air conditioners if not properly maintained. We surveyed the prevalence and risk factors associated with fungal contamination of air conditioners and patient behavior to reduce this contamination. Japanese adults aged ≥ 30 years registered in the database of an Internet research company were asked to participate in an online survey. A moldy odor from the air conditioners in their residences was used as an indicator of fungal contamination. Among a total of 1006 adults, including 631 patients with asthma, 37.1% reported a moldy odor from air conditioners. The prevalence was higher in residences with indoor condensation and in air conditioners used for ≥ 6 years or frequently during the summer, but was lower in air conditioners with an auto-cleaning function. The risk of indoor condensation was higher in apartments, in the presence of an aquarium, and in the absence of a 24-h ventilation system. These risk factors did not differ between the residences or air conditioners of participants with and without asthma. Asthmatic patients were conscious of indoor air quality; however, do not necessarily take appropriate measures to reduce indoor mold contamination, possibly due to a lack of knowledge. In conclusion, appropriate patient education is required to reduce environmental fungal contamination and improve asthma control.

KEYWORDS

air conditioner, asthma, environment, fungi, indoor air quality, ventilation

1 | INTRODUCTION

Fungi are a major environmental allergen.¹ Exposure and sensitization to environmental fungi are associated with asthma onset, severity, and exacerbation.² Furthermore, fungi pose a risk for the development of more severe conditions such as allergic bronchopulmonary aspergillosis/mycosis (ABPA/ABPM). An estimation of the global burden suggested that ABPA develops in approximately five million patients with asthma worldwide.³ As more time is spent at home in the era of the coronavirus disease 2019 (COVID-19) pandemic, appropriate maintenance of the indoor environment is

essential for the health of patients with asthma. However, less is known regarding environmental interventions to reduce indoor molds and their efficacy compared with the approaches for another major indoor allergen, house dust-mites.⁴

Mold growth is affected by temperature, relative humidity, and ventilation. Therefore, heating, ventilating, and air-conditioning (HVAC) systems are beneficial for reducing the burden of airborne fungi.⁵ However, if not properly maintained, air conditioners themselves can be contaminated with fungi and, consequently, spread fungal spores into indoor air.^{6,7} We previously reported a case of ABPM with repeated deterioration due to recurrent exposure to

a contaminated air conditioner. Spontaneous resolution occurred after the environmental trigger was removed.⁸

Moldy odors are derived from fungal or microbial volatile organic compounds (mVOCs), as mixtures of alcohols, aldehydes, acids, ethers, esters, ketones, terpenes, thiols, and their derivatives.⁹ These odors can be a sensitive indicator of the number of airborne fungal spores or β -glucan levels in indoor air.¹⁰ A study in daycare centers demonstrated significantly higher total fungal DNA in dust in the institutes with reported odor.¹¹ In contrast, visible molds are not necessarily associated with airborne fungi or fungal components. A systematic review demonstrated that moldy odor was more closely associated with health outcomes; for example, asthma onset, compared with visible molds, suggesting the clinical importance of invisible fungi detectable with moldy odor. Moldy odor from the air-conditioning systems in automobiles is also associated with fungal contamination of the systems and the vehicles.^{12,13} Therefore, moldy odor from air conditioners may be a reasonable indicator to imply that fungi are a major source of contamination in residences.

We applied an online survey to examine the prevalence of moldy odors from air conditioners in the residences of healthy Japanese participants and patients with asthma and analyze the environmental factors associated with the presence of moldy air conditioners. We then analyzed whether patients with asthma were taking appropriate measures to reduce fungal contamination in the indoor environments of their residences.

2 | MATERIAL AND METHODS

2.1 | Participants

Japanese adults aged ≥ 30 years registered in the database of an Internet research company (Macromill, Inc., Tokyo, Japan) were asked to participate in an online survey performed in October 2020. This survey included 600 patients with asthma and 400 without asthma. Participants who answered yes to both of the following questions were regarded as having asthma and were randomly selected: (1) have you ever been diagnosed with asthma? and (2) are you currently being treated for asthma? Those who answered no to both questions were considered nonasthmatic.

This study was approved by the Institutional Review Board of Tokai University Hospital (20R-179) and was conducted in accordance with the Declaration of Helsinki. Participants provided informed consent by responding to the survey.

2.2 | Questionnaire

The questionnaire comprised 33 questions: 12 on participant characteristics, nine on the home environment, and 12 on air conditioners. The questions regarding participant characteristics included age, sex, living area in Japan, family income, occupation, marital

Practical Implications

Moldy odor in the household air conditioners is associated with the factors related to air conditioners and indoor environments. The present online survey has clarified that patients with asthma, who are vulnerable to fungal exposure, do not necessarily take appropriate measures to reduce indoor mold contamination. Patient education about the maintenance of indoor environment is warranted.

status, number of family members living together, living with children, age at asthma onset, residence type and age, and room to spend the longest.

The questions regarding the home environment included the use of humidifiers/dehumidifiers/air cleaners; the presence of a 24-h ventilation system, aquariums, foliage plants, carpets, and pet breeding; and the occurrence of condensation in the room. The questions on air conditioners asked about the type of room installed, the presence of an auto-cleaning system in the unit, the unit age and frequency of use in the summer and winter months, and the methods and frequency of cleaning the air conditioner, including professional cleaning services.

2.3 | Statistical analysis

Numerical data were presented as means and standard deviations or medians and interquartile ranges (IQRs), while categorical data were presented as numbers and percentages. Group comparisons were performed using Mann-Whitney U and Fisher's exact tests for continuous and categorical variables, respectively. To identify the factors linked to moldy odor or indoor condensation, univariable logistic regression analysis and/or multivariable analysis adjusted for age, sex, and the presence of asthma were performed. The behaviors of the participants with asthma were compared to those of participants without asthma using univariable and multivariable logistic regression analyses adjusted for age, sex, and moldy odor. To predict whether appropriate modification of lifestyle and residential environments can reduce the moldy odor from air conditioners, we calculated the probability of moldy odor on the basis of three models constructed with multivariable logistic regression analysis using data on nonasthmatics. Model #1 included the easily modifiable factors, model #2 included easily modifiable factors and air conditioner-related factors, and model #3 included easily modifiable factors, air conditioner-related factors, and residence-related factors. All the models were adjusted for participant age. Goodness of fit was examined using the Hosmer-Lemeshow test. We then calculated the change in the estimated probability of moldy odor among patients with asthma before and after the removal of specific lifestyle and environmental factors in the model and tested for differences using the Wilcoxon signed-rank test.

The statistical analyses were performed using IBM SPSS Statistics for Windows version 26.0 and GraphPad Prism version 9.0.0 for Windows. Statistical significance was set at $p < 0.05$.

3 | RESULTS

A total of 1006 adults (aged 51.6 ± 12.0 years, 52.6% men), including 631 patients with asthma, responded to the online survey. Most of their residences (94.5%) were equipped with air conditioners, mainly in the living room (90.2%), followed by the bedrooms (50.1%). The median age of the air conditioner was 6.0 years, and approximately one-third of the participants had used the same air conditioner for ≥ 10 years.

A substantial proportion of participants (37.1%) reported moldy odors from their air conditioners. This prevalence did not differ between the residences of asthmatic and nonasthmatic participants. In the nonadjusted univariable analysis, moldy odor was associated with ≥ 4 residents (OR = 1.45, 95% confidence interval [CI] 1.11–1.89), living in apartments (OR = 1.50, 95% CI = 1.01–2.26), and indoor condensation (OR = 2.57, 95% CI 1.96–3.38). Air conditioners ≥ 6 years of age (OR = 2.60, 95% CI 1.75–3.86) and frequent use during the summer (OR = 1.90, 95% CI 1.28–2.81) were related to moldy odors. In contrast, the presence of an auto-cleaning function in the air conditioner significantly reduced the moldy odor (OR = 0.66, 95% CI 0.50–0.85). After adjusting for age, sex, and the presence of asthma, moldy odor was associated with indoor condensation (OR = 2.61, 95% CI 1.97–3.47), air conditioner use ≥ 6 years (OR = 2.33, 95% CI 1.75–3.11), frequent use during the summer (OR = 1.69, 95% CI 1.28–2.24), and auto-cleaning function (OR = 0.62, 95% CI 0.47–0.82) (Table 1). Moldy odor from the air conditioner was significantly associated with cleaning using aerosol spray (OR = 1.69, 95% CI 1.18–2.42) or a professional cleaning service (OR = 1.51, 95% CI 1.14–2.01), regardless of the presence of asthma. These data suggest that the presence of a moldy odor is a major motive for air conditioner cleaning.

Analysis of the factors associated with indoor condensation (Table 2) showed that living in apartments (OR = 1.43, 95% CI 1.10–1.87) and the presence of aquariums (OR = 3.42, 95% CI 1.54–7.56) increased the risk of condensation, while a 24-h ventilation system decreased the risk (OR = 0.38, 95% CI 0.27–0.54).

These data suggested that living in apartments, the presence of an aquarium, older air conditioners, and the frequent use of air conditioners in summer may cause increased exposure to fungi, whereas the presence of a 24-h ventilation system in the residence and auto-cleaning function in the air conditioner reduced exposure. Therefore, we investigated whether patients with asthma were taking appropriate measures to reduce indoor fungal exposure. We found that $< 20\%$ of the residences of patients with asthma were equipped with 24-h ventilation systems. Nearly half of the patients used air conditioners aged ≥ 6 years, half of which were not equipped with auto-cleaning functions (Table 3). Although patients with asthma more

frequently had humidifiers and air cleaners compared to those without asthma, the presence of aquariums, 24-h ventilation systems, old air conditioners, and auto-cleaning functions in the air conditioner did not differ between participants with and without asthma.

The probability of moldy odor, estimated using a combination of lifestyle and environmental factors, was calculated on the basis of the three models (Table S1). Model #1 included the factors that can be modified relatively easily (pet, foliage plant, aquariums, carpet, air cleaner, humidifier, and dehumidifier). Model #2 included the factors from model #1 in addition to air conditioner-related factors (air conditioner age ≥ 6 years and auto-cleaning function). Model #3 included the factors in model #2 and residence-related factors (e.g., apartment, residence ≥ 20 years old). Goodness of fit examined using the Hosmer-Lemeshow test was acceptable for all models. Furthermore, the median values of the estimated probability of moldy odor in patients with asthma were 35–37%, which is close to the actual prevalence (37.7%). Using these models, we calculated the change in the estimated probability of air conditioner moldy odors among patients with asthma before and after the removal of specific lifestyle and environmental factors. Table 4 presents the results of this simulation using model #3. For example, aquariums are present in 25 asthma residences. The probability of moldy odor in these residences as deduced from our model decreased from 0.72 (median) to 0.43 (median, $p < 0.01$) when aquariums as a factor were removed from the model.

Participants with asthma more frequently cleaned their air conditioners by using commercially available aerosol sprays containing detergents and antifungal chemicals (23.6% vs. 15.1%, $p < 0.01$). However, the rate of use of air conditioners with an auto-clean function or professional service to clean the air conditioners with high-pressure washers did not differ from that in patients without asthma (Table 5). After adjusting for age, sex, and moldy odor, participants with asthma more frequently cleaned their air conditioners using commercially available aerosol sprays (OR = 1.48, 95% CI 1.03–2.13) but not with professional services.

4 | DISCUSSION

If not properly managed, air conditioners are a major site of indoor mold growth, possibly causing or worsening ABPM and hypersensitivity pneumonia.^{8,14} The number of airborne fungi increases by 10–10 000 fold immediately after starting a contaminated air conditioner.⁶ Moldy odors originating from air conditioners were present in more than one-third of the residences of participants with and without asthma. Not only air conditioner-related factors, such as length and duration of its use, but also household condensation reflecting high indoor relative humidity were associated with the moldy odor. Asthmatic patients more frequently used air cleaners and humidifiers compared with participants without asthma, implying that they were more conscious of indoor air quality. However, the number of participants who were taking effective measures to reduce moldy odor or condensation,

TABLE 1 Characteristics of indoor environments with or without moldy odor from air conditioners

	Moldy odor from air conditioner		Nonadjusted odds ratio		Adjusted odds ratio ^b	
	With moldy odor	Without moldy odor	Odds ratio	95% CI	Odds ratio	95% CI
<i>n</i>	353	598				
Participant characteristics						
Age of participants (%), years						
30–39	24.4	13.5	Ref			
40–49	33.1	23.4	0.79	0.53–1.16		
50–59	32.0	31.8	0.56**	0.38–0.82		
60–69	7.4	17.1	0.24**	0.14–0.41		
≥70	3.1	14.2	0.12**	0.06–0.25		
Male (%)	42.8	56.9	0.57	0.44–0.74		
Asthma (%)	63.5	62.0	1.13	0.86–1.49		
Age at onset ^a	29 (8–40)	35 (14–49)	0.94**	0.92–0.95	0.99	0.99–1.00
Duration ^a	17.5 (6–33)	18.0 (6–33)	0.94**	0.92–0.96	1.00	0.99–1.01
Residence						
Apartments (%)	42.5	34.4	1.50*	1.01–2.26	1.30	0.99–1.73
Age of residence, years	8 (5–12)	8 (5–12)	1.00	0.97–1.04	0.99	0.97–1.02
0–9	19.8	18.9	Ref			
10–19	22.4	17.9	1.19	0.79–1.81	1.69*	1.07–2.69
≥20	50.4	56.7	0.85	0.59–1.20	1.22	0.84–1.79
Home environment						
Residents ≥4 (%)	48.4	39.3	1.45**	1.11–1.89	1.12	0.85–1.49
Pet (%)	24.1	19.6	1.30	0.84–2.01	1.19	0.86–1.66
Foliage plant (%)	16.7	18.9	0.97	0.59–1.60	0.89	0.62–1.28
Aquariums (%)	5.1	2.7	1.39	0.57–3.35	1.72	0.84–3.49
Carpet (%)	41.4	38.5	0.97	0.67–1.42	1.08	0.82–1.44
24-h ventilation system (%)	17.8	18.9	0.82	0.49–1.37	0.81	0.57–1.15
Air cleaner (%)	35.7	34.2	0.95	0.62–1.45	1.05	0.79–1.40
Humidifier (%)	24.3	19.1	1.09	0.66–1.80	1.34	0.96–1.87
Dehumidifier (%)	10.5	10.9	1.01	0.50–1.88	0.99	0.63–1.54
Condensation (%)	22.9	25.0	2.57**	1.96–3.38	2.61**	1.97–3.47
Air conditioners						
Installed in living room (%)	89.5	90.6	0.90	0.58–1.40	0.87	0.55–1.36
Installed in bedroom (%)	54.4	48.8	1.25	0.96–1.63	1.26	0.94–1.61
Air conditioner age, years						
0–5	36.8	52.8	Ref			
6–10	19.2	17.9	1.54*	1.07–2.23	1.65*	1.12–2.42
11–20	34.8	20.1	2.49**	1.80–3.45	3.04**	2.16–4.30
≥21	8.6	9.2	1.37	0.84–2.23	1.91*	1.14–3.21
Frequent use during the summer (%)	64.3	48.5	1.90**	1.28–2.81	1.69**	1.28–2.24
Use during the winter (%)	66.2	59.9	1.33	0.89–1.99	1.19	0.89–1.58
Auto-cleaning function (%)	42.5	53.0	0.66**	0.50–0.85	0.62**	0.47–0.82
Air conditioner maintenance						
Self-cleaning (%)	82.2	74.2	1.59*	1.15–2.22	1.72*	1.22–2.42

TABLE 1 (Continued)

	Moldy odor from air conditioner		Nonadjusted odds ratio		Adjusted odds ratio ^b	
	With moldy odor	Without moldy odor	Odds ratio	95% CI	Odds ratio	95% CI
Filter alone (%)	57.9	60.3	0.55**	0.39–0.77	0.59**	0.41–0.85
Cleaning with aerosol spray (%)	24.3	13.9	1.83**	1.29–2.59	1.69**	1.18–2.42
Professional cleaning service (%)	41.6	31.8	1.53**	1.17–2.01	1.51**	1.14–2.01

Abbreviations: CI, confidence interval; NS, not significant.

^a Values are medians and interquartile ranges.

^b Adjusted for age, sex, and presence of asthma.

* $p < 0.05$; ** $p < 0.01$.

TABLE 2 Characteristics of the indoor environment with or without dew condensation

	With condensation	Without condensation	<i>p</i> value (univariable)
<i>n</i>	491	482	
Living in apartments (%)	42.2	32.9	<0.01
Number of residents ≥ 4 (%)	23.8	20.1	NS
Pet (%)	21.6	20.5	NS
Foliage plant (%)	17.3	18.7	NS
Aquarium (%)	5.2	1.9	<0.01
Control of indoor air quality and humidity			
24-h ventilation system (%)	11.8	25.7	<0.01
Air cleaner (%)	34.2	35.7	NS
Humidifier (%)	21.8	20.5	NS
Dehumidifier (%)	11.2	10.6	NS

Abbreviation: NS, not significant.

such as auto-cleaning function in air conditioners or 24-h ventilation systems in residences, did not differ between patients with and without asthma. Patients with asthma were more likely to clean air conditioners with aerosol spray, even after adjusting for moldy odor, which is the major motive to clean the air conditioners. However, less than 15% of patients with asthma had asked for professional services to clean their air conditioners by disassembling and high-pressure washing, which effectively removes fungal contamination in the apparatus.

The dew point temperature of outdoor air, a function of temperature and relative humidity, is an important factor for microbial loads in HVAC systems of buildings in the US.¹⁵ Fungal loads on cooling coils are more closely correlated with dew point temperature than bacterial loads, suggesting that moisture is an important factor related to fungal growth. However, window-type (ductless mini-split) air conditioners are commonly equipped in Japanese residences, composed of an outdoor compressor/condenser and an indoor air-handling unit(s), which re-circulate cooled indoor air but do not ventilate with outdoor air. Therefore, indoor environments such as condensation are important for fungal contamination in residences with these air conditioners.

Condensation is an indicator associated with insufficient ventilation and high air humidity, sick building syndrome, asthma exacerbation, and allergic diseases.^{16–18} Our data confirmed that living in an apartment and the use of an aquarium increased the risk of condensation. Most Japanese apartments are reinforced concrete block buildings, which showed higher humidity and more abundant indoor fungi than wooden buildings.¹⁹ In the present study, a 24-h ventilation system suppressed the formation of condensation. As previously discussed, the window-type air conditioners popular in Japan do not ventilate indoor air with outdoor air; therefore, the indoor dew point temperature and the indoor-to-outdoor ratio of fungal bioaerosol levels in the summer are higher in houses equipped with this type of air conditioner compared with residences with HVAC systems.^{16,20} A 24-h ventilation system compensates for the shortcomings of window-type air conditioners.

Patients with asthma more frequently used air purifiers and humidifiers compared with patients without asthma. The use of humidifiers in the winter to increase indoor moisture may prevent respiratory tract viral infections and asthma exacerbation.²¹ However, their use also promotes the growth of fungi and mites, posing a risk of asthma development and worsening.^{19,20} The

	Asthmatics	Nonasthmatics	p value
<i>n</i>	631	375	
Age ^a (years)	51 (42–59)	51 (43–59)	NS
Male (%)	50.6	53.1	NS
Home environment			
Apartments (%)	37.9	38.4	NS
Residences ≥20 years old (%)	60.1	63.7	NS
Pet (%)	23.8	16.8	<0.05
Foliage plant (%)	18.7	16.8	NS
Aquarium (%)	4.1	2.4	NS
Carpet (%)	42.5	35.5	<0.05
Control of indoor air quality and humidity			
24-h ventilation system (%)	18.4	18.1	NS
Air cleaner (%)	36.9	29.9	<0.05
Humidifier (%)	23.5	15.5	<0.01
Dehumidifier (%)	10.9	10.1	NS
Air conditioners			
Years of use ^a	6 (3–10)	6 (3–10)	NS
Use ≥6 years (%)	45.6	45.9	NS
Frequent use during the summertime (%)	52.8	49.1	NS
Use during the wintertime (%)	62.5	61.2	NS
With auto-cleaning function (%)	50.8	49.0	NS
Moldy odor (%)	38.2	35.3	NS

Abbreviation: NS, not significant.

^aValues are median ± interquartile range.

TABLE 3 Comparisons of the characteristics of the indoor environment between patients with and without asthma

estimated probability of moldy odor in the residences of asthmatics who use a humidifier decreased from 0.49 (median) to 0.31 (median, Table 4) if humidifier as a factor was removed from the model, further supporting the notion that patient education can reduce environmental fungal contamination and improve asthma control. Patients with asthma in the present study were also aware of the need for air conditioner maintenance. They not only cleaned the filters but also used an aerosol spray to clean the air conditioners. However, fungal contamination is most prominent in the downstream area of the cooling coils and the blower fan of air conditioners.⁷ Therefore, spraying biocidal detergent cleaner on the front side of the AC heat exchanger has little effect. The cleaning of disassembled air conditioners with a high-pressure washer is most effective in reducing fungal load; however, <15% of patients with asthma utilized professional services for these procedures. Inappropriate efforts by patients themselves to clean air conditioners may exacerbate asthma symptoms.⁸

Online surveys based on moldy odors from air conditioners have some strength in identifying the major factors associated with indoor fungal contamination and patient behaviors regarding these conditions, as they can easily collect data from a large

number of participants with variable backgrounds and lifestyles in a specific season. However, this patient- but not physician-oriented study has several limitations. First, we could not evaluate detailed clinical backgrounds and atopic status, especially sensitization status to fungal allergens. Secondly, although moldy odor is more closely associated than visible fungi with airborne fungal spores/ β -glucan levels¹⁰ as well as with health outcomes in patients with asthma,²² criticisms exist that the source of mVOCs causing "moldy odor" are not necessarily specific to fungi.²³ Thirdly, there was a significant age dependence in the prevalence of moldy odor: Older people reported less moldy odor probably due to the deterioration of olfactory function.²⁴ We, therefore, performed multivariable logistic regression analysis and analyzed the data after adjusting for age to identify the risk factors. Care is still required when using a moldy odor as a parameter of environmental fungal contamination in the elderly population. Field studies examining more detailed clinical backgrounds and environmental parameters such as frequency of air conditioner usage and ventilation can overcome these limitations, however, are limited to small number of samples. Therefore, our study with large samples and other field studies are complementary to each other

TABLE 4 Changes in estimated probability of moldy odor by modification of lifestyle and residential environments

	<i>n</i>	Estimated probability of moldy odor ^a		<i>p</i> value
		Before removal	After removal	
<i>Residence</i>				
Apartments	223	0.43	0.39	<0.01
Residences ≥20years old	323	0.35	0.38	<0.01
<i>Home environment</i>				
Pet	145	0.40	0.36	<0.01
Foliage plant	113	0.30	0.39	<0.01
Aquariums	25	0.72	0.43	<0.01
Carpet	251	0.42	0.34	<0.01
24-h ventilation system	112	0.32	0.45	<0.01
Air cleaner	225	0.36	0.43	<0.01
Humidifier	142	0.49	0.31	<0.01
Dehumidifier	67	0.34	0.41	<0.01
<i>Air conditioners</i>				
Air conditioner age, ≥ 6 years	319	0.47	0.26	<0.01
Auto-cleaning function	291	0.32	0.35	<0.01

^aValues are median.**TABLE 5** Comparisons of the characteristics of the indoor environment between patients with and without asthma

	Asthmatics	Nonasthmatics	<i>p</i> value	Adjusted odds ratio ^a	
				Odds ratio	95% CI
<i>n</i>	631	375			
<i>Air conditioner maintenance</i>					
Self-cleaning (%)	80.8	78.3	NS		
Filter alone (%)	57.2	63.2	NS	0.77	0.59–1.01
Cleaning with aerosol spray (%)	23.6	15.1	<0.01	1.48*	1.03–2.13
Professional cleaning service (%)	36.4	33.2	NS	1.10	0.84–1.47

Abbreviations: CI, confidence interval; NS, not significant.

^a Adjusted for age, sex, and moldy odor.* $p < 0.05$;

to answer the questions about the role of environmental factors on health status in patients with asthma.

5 | CONCLUSIONS

Asthmatic patients were more conscious of indoor air quality. However, they did not necessarily behave appropriately to reduce indoor mold contamination, possibly due to a lack of knowledge. Physicians should provide appropriate information to patients with asthma on how to maintain an optimal indoor environment to minimize fungal contamination.^{25,26}

AUTHOR CONTRIBUTIONS

TO and KA contributed to the conceptualization and the design of the study. NO, YS, and KT performed the statistical analysis and interpretation of the results. NO and KA drafted the

manuscript, and YS, KT, and TO contributed to the critical revision of the manuscript. All authors approved the final version of the manuscript.

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CONFLICT OF INTEREST

KA received lecture fees from AstraZeneca K.K.; Boehringer Ingelheim Co., Ltd.; GlaxoSmithKline plc. Novartis Pharma K.K.; and Sanofi K.K. The other authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The dataset used in this study is available from the corresponding author on reasonable request.

PATIENT CONSENT STATEMENT

Participants provided informed consent by responding to the survey.

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REFERENCES

1. Tanaka J, Fukutomi Y, Shiraishi Y, et al. Prevalence of inhaled allergen-specific IgE antibody positivity in the healthy Japanese population. *Allergol Int*. 2022;71(1):117-124.
2. Masaki K, Fukunaga K, Matsusaka M, et al. Characteristics of severe asthma with fungal sensitization. *Ann Allergy Asthma Immunol*. 2017;119(3):253-257.
3. Denning DW, Pleuvry A, Cole DC. Global burden of allergic bronchopulmonary aspergillosis with asthma and its complication chronic pulmonary aspergillosis in adults. *Med Mycol*. 2013;51(4):361-370.
4. Ahluwalia SK, Matsui EC. Indoor environmental interventions for furry pet allergens, Pest allergens, and Mold: looking to the future. *J Allergy Clin Immunol Pract*. 2018;6(1):9-19.
5. Wu D, Zhang Y, Zhao C, et al. Temporal variation of airborne fungi in university library rooms and its relation to environmental parameters and potential confounders. *Environ Sci Pollut Res Int*. 2021;28(11):14068-14079.
6. Hashimoto K, Oda H, Saito Y, Akimoto M, Nojiri T, Kawakami Y. Isolation of *Simplicillium sympodiophorum* and *Toxicocladosporium irritans* from the blowout air of household air conditioners. *Biocontrol Sci*. 2021;26(2):105-111.
7. Li X, Liu D, Yao J. Aerosolization of fungal spores in indoor environments. *Sci Total Environ*. 2022;820:153003.
8. Okada N, Oguma T, Shiraishi Y, et al. Repeated exacerbation by environmental exposure and spontaneous resolution of allergic bronchopulmonary mycosis. *J Allergy Clin Immunol Pract*. 2021;9(1):558-560.e551.
9. Fischer G, Dott W. Relevance of airborne fungi and their secondary metabolites for environmental, occupational and indoor hygiene. *Arch Microbiol*. 2003;179(2):75-82.
10. Reponen T, Singh U, Schaffer C, et al. Visually observed mold and moldy odor versus quantitatively measured microbial exposure in homes. *Sci Total Environ*. 2010;408(22):5565-5574.
11. Cai GH, Bröms K, Mälarstig B, et al. Quantitative PCR analysis of fungal DNA in Swedish day care centers and comparison with building characteristics and allergen levels. *Indoor Air*. 2009;19(5):392-400.
12. Rose LJ, Simmons RB, Crow SA, Ahearn DG. Volatile organic compounds associated with microbial growth in automobile air conditioning systems. *Curr Microbiol*. 2000;41(3):206-209.
13. Sowiak M, Kozajda A, Jeżak K, Szadkowska-Stańczyk I. Does the air condition system in busses spread allergic fungi into driver space? *Environ Sci Pollut Res Int*. 2018;25(5):5013-5023.
14. Baur X, Richter G, Pethran A, Czuppon AB, Schwaiblmair M. Increased prevalence of IgG-induced sensitization and hypersensitivity pneumonitis (humidifier lung) in nonsmokers exposed to aerosols of a contaminated air conditioner. *Respiration*. 1992;59(4):211-214.
15. Bakker A, Siegel JA, Mendell MJ, Peccia J. Building and environmental factors that influence bacterial and fungal loading on air conditioning cooling coils. *Indoor Air*. 2018;28:689-696.
16. Myers NT, Calderón L, Pavilonis B, et al. Presence and variability of culturable bioaerosols in three multi-family apartment buildings with different ventilation systems in the northeastern US. *Indoor Air*. 2021;31(2):502-523.
17. McConnell R, Berhane K, Gilliland F, et al. Indoor risk factors for asthma in a prospective study of adolescents. *Epidemiology*. 2002;13(3):288-295.
18. Infante-Rivard C. Childhood asthma and indoor environmental risk factors. *Am J Epidemiol*. 1993;137(8):834-844.
19. Meklin T, Hyvärinen A, Toivola M, et al. Effect of building frame and moisture damage on microbiological indoor air quality in school buildings. *AIHA J (Fairfax, Va)*. 2003;64(1):108-116.
20. Moon KW, Huh EH, Jeong HC. Seasonal evaluation of bioaerosols from indoor air of residential apartments within the metropolitan area in South Korea. *Environ Monit Assess*. 2014;186(4):2111-2120.
21. Mäkinen TM, Juvonen R, Jokelainen J, et al. Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. *Respir Med*. 2009;103(3):456-462.
22. Quansah R, Jaakkola MS, Hugg TT, Heikkinen SA, Jaakkola JJ. Residential dampness and molds and the risk of developing asthma: a systematic review and meta-analysis. *PLoS One*. 2012;7(11):e47526.
23. Schleibinger H, Laussmann D, Bornehag CG, Eis D, Rueden H. Microbial volatile organic compounds in the air of moldy and mold-free indoor environments. *Indoor Air*. 2008;18(2):113-124.
24. Doty RL, Shaman P, Applebaum SL, Giberson R, Siksorski L, Rosenberg L. Smell identification ability: changes with age. *Science*. 1984;226(4681):1441-1443.
25. World Health Organization. *WHO Guidelines for Indoor Air Quality: Dampness and Mould*. World Health Organization; 2009.
26. CDC. *You can control mold*. CDC; 2020. https://www.cdc.gov/mold/control_mold.htm

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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