Clinical aspects of allergic disease

House dust mite allergen levels in public places in New Zealand

Kristin Wickens, DPH,[a] Isobel Martin, MPH,[b] Neil Pearce, PhD,[a] Penny Fitzharris, MD,[a] Rachel Kent,[a] Nicki Holbrook, NZCS,[b] Rob Siebers, MIBiol,[a] Stewart Smith, DipMLT,[b] Harry Trethowen, BE,[c] Simon Lewis, BSc,[a] Ian Town, DM,[b] and Julian Crane, FRACP[a]

Wellington, Christchurch, and Porirua, New Zealand

Background: House dust mite allergens are a risk factor for asthma in New Zealand, and levels in domestic dwellings have been found to be high compared with levels in most other countries. Studies in other countries have demonstrated lower levels of *Dermatophagoides pteronyssinus* allergens in public places compared with levels in domestic dwellings.

Objectives: The purpose of this study was to measure reservoir Der p 1 levels in public places in New Zealand and to examine determinants of these levels.

Methods: Reservoir dust was obtained in the two centers (Christchurch and Wellington) from hotels, hospitals, rest homes, churches, primary schools, childcare centers, cinemas, bank head offices, and airplanes; samples were also obtained from ski lodges. Single measurements of temperature and relative humidity were taken with thermohygrometers and an average humidity over 2 weeks was estimated with use of waxed wooden sticks. Information was collected on building construction, type of heating, and frequency of cleaning. Der p 1 levels (micrograms per gram of fine dust) for floor (n = 202), bed (n = 65), and seat (n = 24) samples in public places were expressed as geometric means (95% confidence intervals).

Results: Der p 1 levels in public places were significantly lower than domestic levels in both Wellington and Christchurch. Both floor and bed levels were higher in hotels than in other public places. After controlling for potential confounders, floor Der p 1 levels were higher with carpeted floors (p < 0.0001) and lower with recent cleaning (p = 0.02) and bed Der p 1 levels were higher with timber wall construction (p = 0.03). Other building, heating, or cleaning characteristics did not show significant associations with allergen levels.

Conclusion: Der p 1 levels were much lower in public places than in domestic dwellings with floor levels primarily affected by floor covering. (J Allergy Clin Immunol 1997;99:587-93.)

Key words: Dust mite allergen, public places

House dust mite allergen exposure is a major risk factor for the development[1-3] and provocation[3-5] of asthma in other countries. In New Zealand, 76% of persons with severe asthma have skin prick tests positive for *Dermatophagoides pteronyssinus*[6] and house dust mite sensitivity has been found to be a significant independent risk factor for the development of asthma.[7]

New Zealanders are exposed to high levels of Der p 1 in the home.[8, 9] For example, geometric mean levels as high as 46.6 μg/gm of fine dust have been measured in children's bedding in Wellington.[8] The high 12-month period prevalence of asthma symptoms (26% of adults[10]; 28% of 13 to 14 year olds[11]) may in part be because of this high level of Der p 1 exposure.

Studies in other countries have found low Der p 1 levels in public places compared with levels in domestic dwellings.[12-14] However, these studies have not examined factors that might be responsible for the lower levels.

This study of public places in New Zealand was undertaken to determine whether similarly low levels of Der p 1 occur in public places in New Zealand, to compare these levels with previously measured domestic levels, and to determine the factors that might affect these levels. Ski lodges and airplanes were included to determine whether different climatic conditions in these environments, such as low relative humidity (RH) levels, affected the levels of Der p 1. The study was undertaken in both Wellington and Christchurch because previous studies had found lower levels of Der p 1 in domestic dwellings in Christchurch compared with levels in Wellington.[8, 9]

METHODS

Hotels, hospitals, rest homes, churches, primary schools, childcare centers, cinemas, and bank head offices were ran-

From the Wellington Asthma Research Group, Wellington School of Medicine, Wellington[a]; Canterbury Respiratory Research Group, Department of Medicine, Christchurch School of Medicine, Christchurch[b]; and Building Research Association of New Zealand, Porirua,[c] New Zealand.

The Wellington Asthma Research Group is funded by a Programme Grant from the Health Research Council of New Zealand (Professorial Research Fellowships to JC and NP; Training Fellowship to KW; other grants to RK and SL). The collaboration between the Wellington Asthma Research Group and the Canterbury Respiratory Research Group was supported by the University of Otago. Funding for this study was from The Asthma Foundation of New Zealand. The Electricity Corporation of New Zealand provided financial assistance in establishing an indoor allergen laboratory.

Received for publication May 30, 1996; revised Nov. 5, 1996; accepted for publication Nov. 19, 1996.

Reprint requests: Kristin Wickens, DPH, Wellington Asthma Research Group, Wellington School of Medicine, P.O. Box 7343, Wellington South, New Zealand.

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0091-6749/97 $5.00 + 0 **1/1/79347**

Abbreviations used
AH: Absolute humidity
CI: Confidence interval
RH: Relative humidity

domly selected from appropriate government and private directories for Wellington and Christchurch. A random sample of ski lodges in a central North Island ski area was visited both before and during the winter ski season. A nonrandom sample of airplanes was also visited. National flights were visited in Wellington and international flights were visited in Christchurch. In each urban center 10 of each type of public place were initially sampled, with further numbers randomly selected if the achieved sample comprised fewer than seven eligible respondents for each type of public place. Because of anticipated problems in contacting and accessing ski lodges, 15 were initially sampled.

Visits took place between March and May 1995, with the second (mid-season) visit to ski lodges in September 1995. Wellington and Christchurch visits were matched so that the same types of public places were visited in the same week. Although visits in Wellington and Christchurch were conducted by different researchers, observation of visits by the survey coordinator ensured standardization in collection methods and questionnaire administration among researchers.

Reservoir dust samples were collected from one or two sites in each public place. At least one floor sample of dust was collected. A second floor sample was collected from each respondent for schools, churches, and banks. For hotels, rest homes, hospitals, and childcare centers the second sample was bed dust, and in airplanes and cinemas the second sample was from a seat. Airplanes were sampled while they were on the ground.

Floor samples were collected from 1 m^2 of carpeted floor or 2 m^2 of uncarpeted floor. Bedding samples were a composite of dust from the mattress, pillow, and underbedding, and seat samples were from the top surface of the seat. Each site was sampled for 1 minute with use of a Hitachi CV-2500 vacuum cleaner (1100 watts) modified to collect dust in 25 μm pore-sized nylon mesh bags inserted onto the vacuum head. Der p 1 levels were estimated by a standard monoclonal antibody ELISA.[15] Selected samples were interchanged between Christchurch and Wellington to ensure consistency of ELISA results between laboratories. The between-batch coefficient of variation for Der p 1 was <15% in each center. When the Der p 1 level was undetectably low a value of 0.01 μg/gm was assigned.

At the time of dust sampling a single measurement of RH and temperature was taken at each indoor site and outdoors with portable thermohygrometers (Axiom Data Logging Systems). Wax-coated tongue depressors were also used to calculate a weighted average of RH for approximately the previous 2 weeks. These were taped onto the undersurface of the seat of a chair in the room where the first floor sample was taken. The gravimetric moisture content at the time of recovery was equated to the RH via a known equilibrium moisture content relation for the wood.

Data on building construction, type of heating, and recency of cleaning were collected through interview with either the person in charge of the organization or an appropriate nominee.

The data analysis was conducted separately for floor, bed, and seat samples. The data were approximately log-normally distributed, so all analyses were done with geometric means (with 95% confidence intervals [CIs]). One-way analysis of variance on the log-transformed Der p 1 levels was used to calculate p values in univariate analyses. Multivariate analyses were done with linear regression of the log-transformed Der p 1 levels. The multivariate findings represent a weighted average with equal numbers assumed in each of the categories under consideration. Thus the multivariate geometric means are not directly comparable to the univariate means, but rather are used to make comparisons between categories (e.g., timber compared with concrete floor) while controlling for known confounders.

The study was approved by the Wellington Ethics Committee.

RESULTS

The response rates were 91% in Wellington, 90% in Christchurch, and 47% for ski lodges. Initial analysis of Der p 1 levels in different types of public buildings showed essentially the same patterns regardless of whether geometric mean levels were expressed as micrograms per gram or micrograms per meter squared. Because both the First[1] and Second[16] International Mites and Asthma Workshops have confirmed the use of allergen concentration it was decided to restrict the further analysis to the micrograms per gram measurements. "Do not know" responses are excluded from all tables.

Floor levels

Table I shows significant differences in geometric mean levels of Der p 1 in different types of public places.

Table II shows that in the univariate analysis significantly lower floor Der p 1 concentrations were associated with buildings where windows are not opened (p = 0.02), concrete structural floors (p = 0.0002), central heating (p = 0.0001), uncovered floors (p = 0.0001), and any recent cleaning (p = 0.005). No significant differences were found between Wellington and Christchurch in Der p 1 concentrations. Other characteristics not included in tables but significantly associated with lower levels of Der p 1 in the univariate analysis were centrally controlled air conditioning (p = 0.02), centrally controlled humidity (p = 0.0004), and carpets less than 1 year old (p = 0.02). These were not included in the model because of problems with multicollinearity. There was little or no association between Der p 1 levels and age of the building, roof or wall material, heating source, year-round operation or hours per day of operation, or the temperature setting of central heating. Shampooing or steam cleaning carpets or washing or polishing uncarpeted floors also made no significant difference in floor Der p 1 concentrations.

Mean temperatures, as recorded with thermohygrometers, were 20.4° C indoors and 19.8° C outdoors, and mean RH levels were 58.8% indoors (9.0 gm/kg absolute humidity [AH]) and 60.2% outdoors (9.0 gm/kg AH). Mean RH on the basis of humidity stick data at site 1 only was 52.0% RH. No significant associations were

found between floor Der p 1 levels and temperature or humidity.

For airplanes floor Der p 1 levels were not influenced by the age of the plane, whether international or domestic, or most recent port of call. However, airplanes with RH levels less than the mean had significantly ($p = 0.04$) lower levels of Der p 1 compared with levels higher than the mean.

The key variables were combined in a linear regression analysis (Table II). This analysis excluded ski lodges and airplanes because many of the other variables were not relevant for these places. The analysis showed statistically significant differences for city, type of public place, floor covering, and cleaning recency. Although no longer statistically significant there was still a trend toward lower concentrations of Der p 1 in buildings with some sealed windows, with concrete structural flooring, and with currently running central heating.

Bed levels

Table III shows that bed Der p 1 concentrations were significantly different across types of public places.

Table IV shows that in the univariate analysis lower bed Der p 1 concentration was associated with foam or rubber mattresses ($p = 0.01$), the presence of mattress covers ($p = 0.009$), central heating ($p = 0.002$), concrete floors ($p = 0.005$), and concrete or brick walls ($p = 0.003$) (compared with timber). Other characteristics nonsignificantly associated with higher Der p 1 levels were the presence of a wool underlay, the presence of an electric blanket, and the absence of underbedding (not shown in tables). The age of the mattress and the presence of a layer of foam on the mattress showed no relationship with Der p 1 concentrations.

Mean bedroom RH levels on the basis of thermohygrometer readings were 56.8% (8.9 gm/kg AH) and humidity stick estimates were 50.5%. Mean bedroom temperatures were 20.6° C. Neither temperature nor humidity was significantly related to Der p 1 level although lower concentrations of Der p 1 were associated with temperatures higher than the mean.

Table IV also shows the results of multivariate regression analysis. Only timber wall construction was significantly related to higher bed Der p 1 concentrations, although adjusted values for geometric mean levels of Der p 1 in hotels increased to 5.11 μg/gm and there remained markedly lower levels associated with foam or rubber mattresses and with concrete floors.

Seat levels

Univariate analysis showed seat Der p 1 concentrations to be significantly lower in airplanes than in cinemas. Low RH levels were also significantly associated with low seat Der p 1 concentrations. Although these effects lost their significance in the multivariate analysis, levels of Der p 1 found in the low-humidity environment of airplanes were still half the levels found in cinemas (Table V).

TABLE I. Geometric mean Der p 1 concentrations on floors by type of public place

Type of public place	N	Geometric mean (μg/gm)	95% CI	*p* Value
Hotels	15	5.26	2.06-13.41	0.0001
Hospitals	19	0.14	0.04-0.51	
Rest homes	16	0.97	0.32-2.96	
Churches	29	1.54	0.71-3.34	
Schools	38	0.98	0.61-1.56	
Childcare	17	0.22	0.08-0.61	
Cinemas	13	1.11	0.54-2.26	
Banks	26	0.11	0.05-0.25	
Airplanes	14	0.29	0.18-0.47	
Ski lodges	15	0.61	0.22-1.69	
Total	202	0.58	0.43-0.79	

Ski lodges

Ski lodge floor Der p 1 levels (0.61 μg/gm [0.22 to 1.69]) were not significantly influenced by season with geometric mean levels of 0.43 μg/gm (0.05 to 3.56) at the preseason visit in April and 0.83 μg/gm (0.25 to 2.74) during the ski season in September. Bed levels were high (2.71 μg/gm [0.77 to 9.55]) compared with those in urban centers, with a trend ($p = 0.08$) toward higher levels in the winter (7.49 μg/gm [1.70 to 32.93] compared with 0.98 μg/gm [0.12 to 8.32] in the summer) possibly reflecting increased occupation during the ski season. The altitudes of the ski lodges ranged from 1260 to 2200 m above sea level. Although temperature and humidity measurements were not found to be associated with Der p 1 levels, summer floor levels and winter bed levels were lower in lodges at higher altitudes than those in lodges at lower altitudes ($p = 0.003$, $r = -0.71$, and $p = 0.03$, $r = -0.80$, respectively). Floor concentrations >2 μg/gm were not found above 1680 m, although one ski lodge at 1750 m contained a level of 2.83 μg/gm in the bedding.

DISCUSSION

Levels of Der p 1 in public places were much lower than those previously found in domestic dwellings. For example, the geometric mean level of floor Der p 1 was 0.58 μg/gm (0.43 to 0.79) in public buildings compared with geometric mean levels on living room floors of 25.40 μg/gm (22.70 to 28.40) in Wellington and 3.45 μg/gm (2.49 to 4.78) in Christchurch and with those on bedroom floors of 26.00 μg/gm (23.40 to 28.90) in Wellington and 10.13 μg/gm (7.52 to 13.67) in Christchurch.[8, 9] The geometric mean level of Der p 1 in beds was 1.20 μg/gm (0.65 to 2.21) in public places compared with 46.30 μg/gm (42.00 to 51.00) in beds in Wellington and 5.70 μg/gm (4.30 to 7.60) in Christchurch. Thus even the lower levels found in domestic dwellings in Christchurch, compared with Wellington, were much higher than levels found in public places. Furthermore, although there were major differences in Der p 1 levels between different types of public places, all of the analyses of various types and characteristics of public places found lower levels than had been found

TABLE II. Linear regression analysis of geometric mean Der p 1 concentration on floors

	N	Univariate geometric mean (μg/gm)	95% CI	Multivariate geometric mean (μg/gm)	95% CI	*p* Value
City						
Wellington	82	0.68	0.39-1.20	1.03	0.40-2.66	0.03
Christchurch	91	0.56	0.38-0.83	0.54	0.21-1.35	
Type of public place						
Hotels	15	5.26	2.06-13.41	3.60	0.86-15.15	0.0002
Hospitals	19	0.14	0.04-0.51	0.74	0.22-2.49	
Rest homes	16	0.97	0.32-2.96	1.08	0.29-3.99	
Churches	29	1.54	0.71-3.34	1.07	0.36-3.16	
Schools	38	0.98	0.61-1.56	0.44	0.14-1.32	
Childcare	17	0.22	0.08-0.61	0.23	0.07-0.79	
Cinemas	13	1.11	0.54-2.26	1.29	0.31-5.28	
Banks	26	0.11	0.05-0.25	0.23	0.07-0.82	
Windows						
None opened	45	0.30	0.15-0.60	0.67	0.22-2.06	0.64
Some opened	59	0.65	0.37-1.13	0.65	0.25-1.74	
All opened	83	0.91	0.57-1.45	0.94	0.34-2.58	
Floor material						
Timber	77	1.27	0.80-2.00	0.81	0.31-2.12	0.59
Concrete	108	0.37	0.24-0.57	0.68	0.26-1.75	
Central heating						
Currently running	60	0.21	0.12-0.36	0.49	0.17-1.41	0.33
Not currently running	43	0.83	0.47-1.45	1.00	0.35-2.85	
No central heating	84	1.14	0.70-1.85	0.83	0.31-2.23	
Floor covering						
Carpet/rug	157	0.95	0.70-1.29	3.21	1.36-7.56	0.0001
No carpet/rug	31	0.07	0.03-0.15	0.17	0.06-0.54	
Cleaning recency						
<3 Days ago	131	0.42	0.28-0.62	0.19	0.11-0.31	0.02
3 Days-1wk ago	38	1.57	0.91-2.69	0.49	0.22-1.08	
>1 Wk-1 mo ago	5	2.66	0.08-83.49	1.50	0.19-12.06	
>1 Mo ago	5	0.62	0.07-5.68	2.20	0.18-26.76	

Table excludes ski lodges and airplanes because not all variables were relevant for these places.

TABLE III. Geometric mean Der p 1 concentration in beds by type of public place

Type of public place	N	Geometric mean (μg/gm)	95% CI	*p* Value
Hotels	15	3.57	1.54-8.28	0.0001
Hospitals	15	0.10	0.02-0.47	
Rest homes	16	2.03	0.75-4.49	
Child care	5	1.49	0.40-5.58	
Ski lodges	14	2.71	0.77-9.55	
Total	65	1.20	0.65-2.21	

in domestic dwellings. For example, public places in New Zealand are more often centrally heated, are cleaned more regularly, and often have different construction characteristics than domestic dwellings, but even the public places that did not have these characteristics had much lower levels than domestic dwellings. Thus it appears that other factors, such as differences in intensity and patterns of occupation, may also contribute to the lower levels of Der p 1 in public places. However, because of the different functions of each type of public place, we were not able to adequately measure the effect of different occupancy levels.

For many variables there was considerable heterogeneity between the various public buildings. For example, hotels were less likely to be centrally heated than any other building type. This heterogeneity produced multicollinearity in the multivariate analysis, leading to wider CIs. For example, the overall findings for floor levels in Christchurch were relatively unchanged in the multivariate analysis (Table II) but the CI (0.21 to 1.35) was much wider than that for the univariate analysis (0.38 to 0.83). In this context, hotels had much higher levels of floor and bed Der p 1 compared with other public places. Multivariate analysis was unable to explain the reasons for the higher levels, which suggests that characteristics we did not measure may be responsible. The high bed Der p 1 levels in hotels may be partly explained by the inclusion of a single high bed Der p 1 result from Wellington in the analysis. However, outliers do not contribute to the higher floor levels found in hotels.

The growth of house dust mite populations has been positively correlated with indoor humidity in other countries measured both at one time and averaged over a period of time.[17, 18] However, neither measurement of RH in our study correlated with Der p 1 levels, perhaps

TABLE IV. Linear regression analysis of geometric mean Der p 1 concentration in beds

	N	Univariate geometric mean (μg/gm)	95% CI	Multivariate geometric mean (μg/gm)	95% CI	*p* Value
City						
Wellington	26	0.93	0.26-3.39	1.28	0.42-3.89	0.98
Christchurch	25	0.99	0.53-1.85	1.26	0.44-3.60	
Type of public place						
Hotels	15	3.57	1.54-8.28	5.11	0.76-34.50	0.13
Hospitals	15	0.10	0.02-0.47	0.39	0.09-1.58	
Rest homes	16	2.03	0.75-4.49	0.92	0.25-3.33	
Child care	5	1.49	0.40-5.58	1.43	0.12-16.84	
Plastic/rubber mattress cover						
Completely surrounds	20	0.38	0.09-1.63	0.81	0.15-4.41	0.80
Partly covers	8	0.44	0.10-1.90	1.57	0.19-13.04	
No plastic/rubber sheet	37	2.45	1.37-4.38	1.60	0.63-13.04	
Mattress type						
Foam/rubber	31	0.61	0.21-1.71	0.70	0.16-3.05	0.29
Inner spring	30	2.97	1.59-5.55	2.29	0.60-8.76	
Central heating						
Currently running	22	0.39	0.14-1.08	0.87	0.32-2.38	0.67
Not currently running	9	0.46	0.07-3.14	1.95	0.35-10.99	
No central heating	34	3.22	1.51-6.85	1.20	0.37-3.92	
Floor construction						
Concrete	40	0.68	0.32-1.46	0.94	0.36-2.45	0.38
Timber	24	3.73	1.53-9.12	1.71	0.48-6.13	
Wall construction						
Fiber-reinforced cement	3	0.16	0.00-62.04	0.86	0.11-6.79	0.03
Timber	24	4.97	2.03-12.17	11.08	2.28-53.77	
Concrete	17	0.56	0.17-1.81	0.33	0.09-1.18	
Brick	17	0.45	0.13-1.52	0.98	0.28-3.39	
Other	4	1.92	0.21-17.4	1.08	0.19-6.05	

Table excludes ski lodges because not all variables were relevant to lodges.

TABLE V. Linear regression analysis of geometric mean Der p 1 concentration on seats

	N	Univariate geometric mean (μg/gm)	95% CI	*p* Value	Multivariate geometric mean (μg/gm)	95% CI	*p* Value
Type of public place							
Airplanes	14	1.62	0.89-2.93	0.008	2.10	1.10-4.00	0.25
Cinemas	10	6.12	2.58-14.51		4.26	1.87-9.70	
Thermohygrometer RH							
≤ mean (51.5%)	12	1.41	0.76-2.61	0.005	1.90	0.86-4.15	0.14
> mean (51.5%)	12	5.61	2.63-11.96		4.71	2.37-9.35	

because mean annual outdoor RH, at higher than 80% in Wellington and Christchurch, is most often above the threshold required for mite survival. Alternatively, it is possible that both methods are inadequate indicators of the long-term mean RH found in the more humid microenvironments (beds, carpets) that mites colonize.

Timber floor construction was associated with raised levels of Der p 1 on the floors and beds of public places, and timber walls were associated with high bed levels. Similar associations between increased Der p 1 concentrations and wooden floor construction (versus concrete floor construction) have previously been reported in Holland[19] and in New Zealand.[20] Cunningham (Building Research Association of New Zealand, unpublished data) suggested that RH levels are higher on wooden floors because outdoor conditions have a greater influence on wooden compared with concrete-slab floors. If high humidity is associated with high Der p 1 concentrations, then this could explain the higher Der p 1 levels found associated with timber compared with concrete constructions.

Although studies have documented the benefits of ventilation in lowering levels of Der p 1[18, 21] this may be ineffective in buildings with dampness problems[18] or those in a constant high humidity environment such as New Zealand. This may explain why increased ventila-

tion was not found to be associated with lower Der p 1 levels in this study. On the other hand, buildings with sealed windows are more likely to be centrally heated. In this study lower Der p 1 concentrations were associated with currently running central heating, especially when systems both heated and cooled or controlled RH. In a German study underfloor heating was significantly associated with lower levels of mattress Der p 1.[17] The authors suggested that underfloor heating alters indoor climates so that environments become less hospitable to dust mites. Central heating may do the same thing. Lower RH levels were associated with currently running central heating (56%) compared with buildings where central heating was not running (62%) and buildings with no central heating (61%). These results suggest that if central heating operated continuously it might reduce humidity and therefore be beneficial in lowering Der p 1 concentrations. However, this is not a practical option in a temperate climate such as New Zealand.

Lower floor levels were significantly associated with recent cleaning in both the univariate and the multivariate analysis, indicating that one reason for lower levels of Der p 1 in public places, compared with those in domestic dwellings, might be more frequent cleaning. The results of studies on the effects of vacuuming in the domestic environment have been inconsistent. In a Wellington study of domestic dwellings recent vacuuming did not affect Der p 1 levels.[8] However, frequent vacuuming of domestic homes in Holland was associated with lower Der p 1 levels.[19]

The strongest association with Der p 1 levels was for floor covering. The finding of much higher levels in carpets or rugs, compared with those on uncovered floors, is consistent with findings from studies in other environments[8, 19] and may be clinically important because improvements in asthma symptoms in children sensitive to dust mites have been measured after carpet removal.[22]

Bed levels of Der p 1 were higher than floor levels in public places but significantly lower than those found in domestic beds. The greater use of mattress covers in public places compared with domestic dwellings may partly explain the large differences between levels of Der p 1 in public and domestic bedding. However, public places that do not use mattress covers, for example, hotels, also have lower levels than those in domestic homes. The reasons for this remain unexplained.

No significant differences were found between Christchurch and Wellington public places until possible confounders were controlled for. The higher levels found on Wellington floors after modeling are unlikely to be explained in terms of different outdoor RH levels because both centers have similarly high humidity levels (82% in Wellington and 85% in Christchurch; personal communication, National Institute of Water and Atmospheric Research). However, Christchurch has lower mean winter temperatures. Increased heating, which would lower indoor humidity, might therefore explain the lower levels of Der p 1 found in Christchurch. Significant differences between mean indoor RH levels at Wellington floor sites (62%) compared with Christchurch floor sites (58%) as measured by thermohygrometers in this study support this hypothesis.

In conclusion, this study strongly suggests that reservoir Der p 1 levels can be greatly reduced by the removal of carpets and by frequent cleaning. Further studies are needed to determine the clinical benefits of such interventions. Heating systems and building construction materials might also contribute to lower levels of Der p 1 in public places and these require further study in domestic dwellings.

We thank Malcolm Cunningham, Building Research Association of New Zealand, for his advice on the humidity and thermal conditions of buildings. Additional tables showing more detailed results are available from the authors.

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