

Original article

Major mite allergen Der f 1 concentration is reduced in buildings with improved energy performance

Background: Environmental conditions play a crucial role in mite growth, and optimal environmental control is key in the prevention of airway inflammation in chronic allergic rhinoconjunctivitis or asthma.

Objective: To evaluate the relationship between building energy performance and indoor mite allergen concentration in a cross-sectional study.

Methods: Major allergen concentration (Der f 1, Der p 1, mite group 2, Fel d 1 and Bla g 2) was determined by quantitative dot blot analysis from mattress and carpet dust samples in five buildings designed for low energy use (LEB) and in six control buildings (CB). Inhabitants had received 4 weeks prior to mite measurement a personal validated questionnaire related to the perceived state of health and comfort of living.

Results: Cumulative mite allergen concentration (with Der f 1 as the major contributor) was significantly lower in LEB as compared with CB both in mattresses and in carpets. In contrast, the two categories of buildings did not differ in Bla g 2 and Fel d 1 concentration, in the amount of dust and airborne mould collected. Whereas temperature was higher in LEB, relative humidity was significantly lower than in CB. Perceived overall comfort was better in LEB.

Conclusions: Major mite allergen Der f 1 preferentially accumulates in buildings not specifically designed for low energy use, reaching levels at risk for sensitization. We hypothesize that controlled mechanical ventilation present in all audited LEB may favour lower air humidity and hence lower mite growth and allergen concentration, while preserving optimal perceived comfort.

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Energy saving is a major objective of most industrialized countries. The relationship between building energy consumption and indoor mite load has been the object of controversies. In the 1970s, attempts to decrease energy losses by occluding most of a building's openings led to impaired ventilation and increased humidity, conditions that favoured mite growth (1–3). However, novel concepts in building construction including high performance mechanical ventilation systems with heat recovery have largely modified the strategies of energy savings, allowing a reduction in annual consumption of <42 kWh/m² floor area for heating and hot water in optimal conditions (Minergie® label, <http://www.minergie.ch/>).

Perennial exposure to mite allergens is a major risk major risk for people/individuals with chronic allergic rhinoconjunctivitis and asthma (4), and the dose–response relationship between mite exposure, sensitization and disease severity is well accepted (5–7). The demonstration of the efficacy of avoidance measures on the severity of airway hypersensitivity is, however, still

controversial (8–10). Limited to mattress encasings, avoidance measures appear to fail to improve both rhinoconjunctivitis and asthma (11, 12). In contrast, combined measures including mattress and bedding encasing, regular vacuum cleaning and acaricide treatment led to decrease in mite load in the indoor environment, and in the indoor environment, which was in parallel with improvement of bronchial hyperreactivity in children with asthma (13). Nonetheless, a general consensus has not yet been reached (14). Earlier studies clearly indicated that a strict avoidance of mite exposure such as patient therapy in high altitude stations where mites are rare or inexistent (Davos, Switzerland or Briançon, France) (15–17) or in environments free of mites led to clinical improvement of the patients (18). The capacity of the immune system to be fully activated with residual amounts of mite allergens (ng level) may partially explain the relative inefficacy of mite avoidance measures in limiting allergic inflammation of the airways. In this context, any decrease in the load of mite allergens in the indoor environment may contribute to further amplifying

the effect of individual avoidance measures and to potentially improving patients' allergic symptoms. The present study aimed to examine, in a cross-sectional design, whether optimal energy saving measures including mechanical ventilation combined with heat recovery may reduce relative humidity in apartments, and finally result in reduced mite growth and improved quality of life for mite allergic patients.

Methods

Study design

The HOPE project (EU contract number ENK6-CT-2001-00505, Health Optimisation Protocol for Energy-efficient Buildings) was devised as a prenormative and socio-economic research to create healthy and energy-efficient buildings. In this framework, a sub-project in Lausanne, Switzerland, aimed to evaluate the relationship between buildings specifically designed for low energy use and indoor mite level. Physical characteristics of a series of buildings ($n = 97$) were collected in the frame of the HOPE Project (19, 20). From this list, 11 well characterized buildings (among 28) were selected, five especially designed for low-energy use (LEB) and six control buildings (CB). Buildings classification was based on energy performance index that is the total yearly energy use per square meter (low energy use $\leq 140 \pm 10$ kWh/m²), and furthermore on the presence or the absence of specific energy saving measures such as mechanical ventilation with heat recovery, optimal measures for thermal insulation of walls and windows (double glazing etc), absence of thermal bridges (Table 1). Buildings were comparable for several major characteristics (Table 1), although there was some (statistically nonsignificant) difference in age at completion because of the fact that the energy use in buildings changed with the year of construction: all recent buildings used much less heating energy than older ones. All buildings were located in the Lausanne area,

and both environmental characteristics and socio-economical status of inhabitants (middle to upper middle class level) from LEB and CB were comparable. LEB had all an improved thermal insulation of walls and windows, a mechanical ventilation system in all rooms with heat recovery from exhaust air and passive solar design. Buildings of the CB group were naturally ventilated through infiltration and window openings. The energy consumption index (annual total energy use per heated floor area) was 129 ± 18 kWh/m² (mean $\pm$ SD) for LEB, as compared with 200 ± 45 kWh/m² in CB ($P = 0.03$). When electricity use was not taken into account (i.e. heating fuel only), energy consumption indexes were 87 ± 15 kWh/m² for LEB vs 157 ± 45 kWh/m² for the control group ($P < 0.01$).

A personal validated questionnaire for adults or children was mailed to each of the 556 inhabitants (277 apartments) of the LEB group, and to each of the 730 inhabitants (314 apartments) of the CB group 4 weeks prior to mite sampling. This questionnaire included a 'Health questionnaire' related to the perceived state of health and comfort by the occupants of the apartments as well as a 'Household questionnaire', related to environmental and technical characteristics of the apartment and its equipment (21). Comfort evaluation in buildings included thermal, acoustical and visual comfort as well as indoor air quality. Perceived comfort was the result of the evaluation of these various items by the occupants, assessed by a questionnaire. A significant proportion of inhabitants chose to remain nontraceable and returned the questionnaire: 174 (31% of inhabitants) from 115 apartments in the LEB group and 281 (38% of inhabitants) from 174 apartments in the CB group. When traceable, they were asked authorization for a visit of their apartment by a trained investigator (MB) who performed measurements from December to following March. In the LEB group, 35 apartments from the five buildings (73 inhabitants) were visited (30%) (Table 2). Fifty-four were nontraceable, 20 owners refused the visit or did not respond and six had moved. In the CB group, 43 apartments from the six buildings (108 inhabitants) were visited (25%). One hundred and eleven apartments were nontraceable, seven owners refused the visit or did not respond, and 13 had moved. Dust collection from both groups of building was equally distributed along the 4-month period to avoid sampling bias. The Ethical Review Board

Table 1. Building characteristics

	Code	Year	Location	Energy index (kWh/m ²)	Floors (n)	Apartments (n)	Occupants (n)	Floor area (m ²)
LEB	3	1973	Suburb	103	8	137	211	9360
	5	1999	Suburb	119	3	7	15	600
	6	1996	Suburb	133	5	82	180	9546
	9	1988	City	142	7	27	80	2160
	8	1992	City	149	7	24	70	2400
Total					30	277	556	24 066
Mean		1990		129	6	55	111	4813
CB	2	1994	Suburb	140	4	106	250	8824
	10	1962	Suburb	170	4	23	50	1232
	4	1973	Suburb	211	4	56	100	3996
	1	1980	Country	233	3	28	90	6566
	7	1994	City	248	5	16	40	2352
	14	1974	Suburb	*>200	13	85	200	7020
Total					33	314	730	29 990
Mean		1980		200	6	52	122	4998

*Not included in mean. Minimal energy index estimation for this building; LEB, low-energy use buildings; CB, control buildings.

Table 2. Number of apartments visited per building type and distribution of inhabitants per age and gender *mean $\pm$ SD of individual ages

	Code number	Visited apartments (n)	Adults (n)	Children (n)	Male (n)	Female (n)	Mean age	SD
LEB	3	15	22	6	11	17	50	28
	5	6	10	4	8	6	33	19
	6	7	12	5	7	10	36	25
	9	5	10	1	6	5	38	14
	8	2	3	0	1	2	47	8
Total		35	57	16	33	40		
Mean		7	11	3	7	8	*41	*24
CB	2	7	7	0	4	3	21	2
	10	2	5	1	3	3	50	37
	4	10	17	8	13	12	39	23
	1	14	27	18	20	25	44	20
	7	2	4	2	3	3	33	17
	14	8	17	2	12	7	28	20
Total		43	77	31	55	53		
Mean		7	13	5	9	9	*38	*21

of the Faculty of Biology and Medicine, Lausanne, Switzerland approved the study protocol, and participants filled a written informed consent.

Dust collection and allergen measurement

Dust collection, allergen extraction and measurement were performed with adaptation to methods previously described (22, 23). Briefly, dust was collected separately from mattresses and carpets of the sleeping room using a dust collector (integrated to a vacuum cleaner > 1000 W) equipped with a Nylon filter with a pore size of 40 µm. Four areas of 22 × 30 cm were aspirated separately on mattresses as well as on carpets for 30 s each. Filters were weighed on a Mettler Toledo precision balance (Viroflay, France), and allergen extract from dust was prepared by agitation for 60 min in 10 ml extraction buffer (0.125 M ammonium hydrogen carbonate) at room temperature. The filter was discarded and the supernatant centrifuged for 10 min at 5000 rpm. Supernatants were frozen at -20°C, until tested for major allergens from *Dermatophagoides pteronyssinus* (Der p 1) and *Dermatophagoides farinae* (Der f 1), for group 2 *Dermatophagoides* allergens (MG2), for major cat allergen (Feld d 1) and major cockroach allergen (Bla g 2) using a quantitative dot blot assay (Heska TM Dustscreen TM0 Assay, Fribourg, Switzerland) as previously described (22, 23). Dot density was measured using a FAG VIPDENS 111 densitometer (CMG-Heska, Fribourg, Switzerland) and quantified using a precalibrated standard curve for each allergen. According to the weight of the dust sample and the volume of extraction buffer, results are expressed as ng/g of dust.

Sampling of airborne moulds

Air sample collection was performed using a MAS-100 Eco air sampler (MBV AG CH 6014 Littau, Switzerland) with preset volumes for two air samples of 100 and 500 l respectively per apartment. Aspirated moulds were grown in Petri dishes filled with a 39% Potato-Glucose Gelose (Oxoid Ltd., Basingstoke, Hampshire, UK) containing ampicilline 50 µg/ml for 3–5 days at room temperature, then maintained for 5 days at 4°C. Colony forming units (CFU) were counted manually.

Humidity and temperature measurement

The air humidity was measured during each visit using an aspiration psychrometer (Haenni & Cie. AG, CH 3303 Jegenstorf, Switzerland). Psychrometric measurement was chosen for being a highly reproducible reference methodology (24). Temperature (dry air temperature) was measured during the same visit using two calibrated (0.2°C divisions) mercury thermometers incorporated in the psychrometer and ventilated in order to obtain an air velocity larger than 2 m/s around the bulbs of the thermometers.

Statistical analysis

Data were analyzed using an INSTAT 3.1 software (GraphPad Software, La Jolla, CA, USA). 'Cumulative mite allergen concentration' designated the sum of concentration of the various mite species measured in each apartment, i.e. Der p 1, Der f 1 and MG2. Nonparametric analysis (Mann–Whitney test) was applied to statistical analysis of differences in allergen concentrations and the unpaired *t* test with Welch correction for differences in temperature and relative humidity between LEB and CB.

Results

Indoor allergen concentration in LEB vs control buildings

The largest difference in mite allergen concentration was found in mattresses for Der f 1, with a median of 954 ng/g of dust (5th to 95th percentile: 2.1–5471 ng/g) in the CB group compared with 67 ng/g (undetectable to 1356 ng/g) in the LEB group ($P < 0.0004$) (Fig. 1A). These data were consistent with the significant difference in Der f 1 concentration also measured in carpets although lower of approximately one log 10. In carpets of the CB group, Der f 1 concentration was 174 ng/g (21–4873 ng/g) as compared with 20 ng/g (undetectable to 1972 ng/g) in the LEB group ($P < 0.005$). In contrast, Der p 1 was found in limited amounts both in mattresses and carpets, and in similar concentrations in the CB group (in mattresses, median 73 ng/g (4–1433 ng/g); in carpets, median 22 ng/g [undetectable to 1193 ng/g]) and LEB group [in mattresses, median 51 ng/g (2–923 ng/g); in carpets, median 12 ng/g (undetectable to 105 ng/g)] ($P = 0.6$ and 0.2 ,

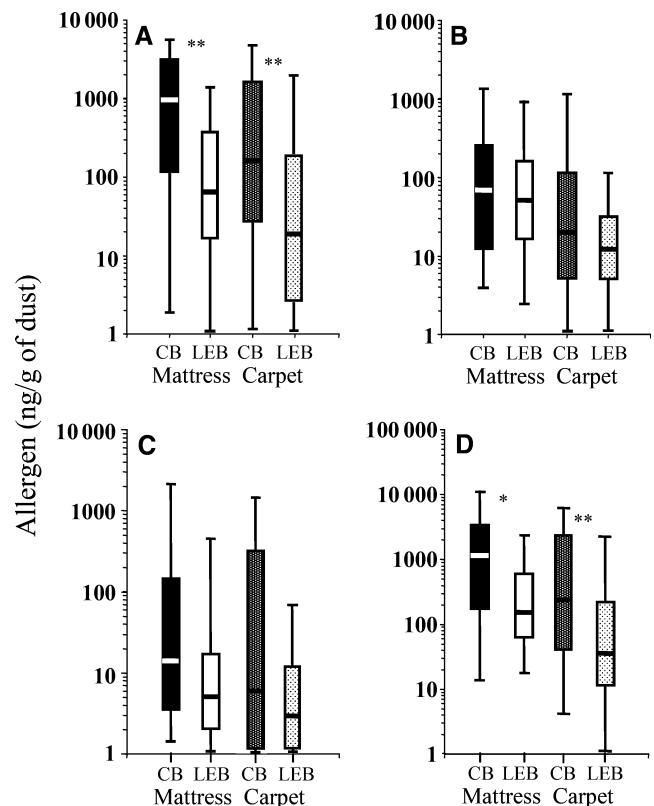


Figure 1. Mite allergens are significantly less abundant in LEB than in CB groups. Allergen concentration in ng/g of dust in mattresses and carpets of CB and LEB apartments. (A) Der f 1, (B) Der p 1, (C) Mites group 2, (D) Cumulative amount of Der f 1, Der p 1 and mites group 2. Data are expressed as median (plain bar), plot boxes (percentiles 25 and 75) and whiskers (percentiles 5 and 95) and analyzed by a Mann–Whitney test * $P < 0.05$, ** $P < 0.01$.

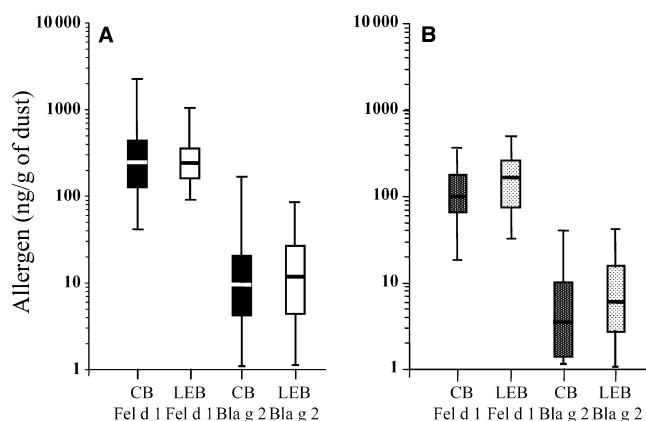


Figure 2. Concentration of cat (Fel d 1) and cockroach (Bla g 2) allergens in LEB vs CB groups. (A) in mattresses, (B) in carpets. Data are expressed and analyzed as in Fig. 1. There was no significant difference between groups.

respectively, Fig. 1B). Median concentration of mite group 2 allergens (MG2) was also low and was not found significantly different in mattresses (15 ng/g vs 5 ng/g) or carpets (6 ng/g vs 3 ng/g) from CB vs LEB groups ($P > 0.05$, Fig. 1C). Totally, the cumulative amount of major allergens Der f 1 and Der p 1 and MG2 was significantly increased in CB in mattresses [$P = 0.003$, median 1071 ng/g (14–12 090 ng/g) in CB vs 175 ng/g (17–2269 ng/g) in LEB], as well as in carpets [$P = 0.004$, median 251 ng/g (4–6844 ng/g) in CB vs 36 ng/g (undetectable to 1992 ng/g) in LEB]. These data are in agreement with individual groups' findings for mite allergens (Fig. 1D). As control allergens, the level of major cat allergen Fel d 1 and of cockroach Bla g 2 in dust were found in comparable concentrations in CB and LEB, both in mattresses and carpets (Fig. 2A, B).

Perceived health and comfort

The occupants (adults only) were asked by questionnaire whether they had signs or symptoms suggestive of allergy (perceived health). In LEB, 17 of 57 adult inhabitants were complaining of at least one of the following potential diagnosis (asthma, wheezing, hay fever, allergic rhinitis, eczema), as compared with 16 of 77 among CB adult inhabitants (Fisher's test, $P = 0.3$). Nonetheless, when we considered apartments of occupants with ($n = 19$) vs without symptoms or signs suggestive of allergy ($n = 59$), the concentration of Der f 1 in mattresses as well as in carpets was significantly higher ($P < 0.05$ and $P < 0.01$ respectively) in apartments of occupants with allergy suggestive symptoms. Inhabitants were also asked questions on the perceived indoor environment quality (perceived overall comfort), perceived indoor air quality as well as perceived thermal comfort. Complete results for all audited European buildings are described elsewhere (19, 20). For the

building groups studied in this paper, there was a very clear difference between LEB and CB groups. On a scale running from 1 (very satisfactory) to 7 (unsatisfactory), the perceived overall comfort was, on the average, respectively, 2.0 and 2.6 ($P = 0.01$); the air quality in winter 2.0 and 2.5 ($P = 0.006$) and the temperature in winter 2.9 and 3.6 ($P = 0.007$).

Temperature and relative humidity

To identify the environmental factors responsible for the difference in mite concentration observed between CB and LEB, wet and dry temperatures were measured using a psychrometer (24, 25). Although the difference was weak, dry temperature was higher in LEB than in CB (mean 21.7°C vs 20.6°C, $P = 0.009$, Fig. 3). The calculated mean relative humidity was 46% in LEB and 57% in CB ($P = 0.01$). These data strongly suggested that despite a mild difference in temperature in favour of LEB, the lower relative humidity measured in LEB was associated with lower concentrations of mite allergens in dust collections, presumably related to a less favourable growth environment for mites than the higher relative humidity prevalent in CB. In support of this hypothesis, occupants were asked if areas of condensation were present in their apartments. Areas of condensation were reported in only four of the 32 LEB apartments, contrasting with 12 of the 33 CB apartments who replied to this question (Fischer's test, $P = 0.04$). Mould growth was observed in 18% of the bathroom ceilings in CB and only 3% in LEB. Despite a higher relative humidity in CB, there were no differences between building groups in the number of mould CFU and mould species distribution in air samplings collected by the MAS-100 Eco air sampler (data not shown). Potential confounding factors were examined including the quantity of dust collected in mattresses or carpets from CB or LEB, the use of mattress encasings, the presence of animals per apartment including cats and the number of smokers, and were not found different between LEB and CB (data not shown).

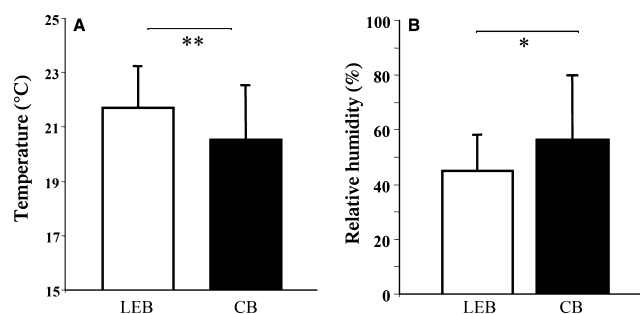


Figure 3. Dry temperature and relative humidity. (A) Dry temperature, (B) relative humidity in % in CB vs LEB. Open columns: LEB, black columns: CB. * $P = 0.01$, ** $P < 0.01$.

Discussion

Mite growth is strongly dependent on ambient humidity; optimal growth conditions require at least 55% relative humidity (26) and a temperature of 22–26°C. Because of relatively strong winters, Lausanne, Switzerland, at plain level and close to the Geneva Lake, provides rather unfavourable conditions for mites growth, particularly for *Dermatophagoides pteronyssinus*, more sensitive to low humidity and temperature than *Dermatophagoides farinae* (27). Accordingly, humidity and temperature levels were not sufficiently high to strongly stimulate growth of moulds, a finding in agreement with the very low prevalence of allergy to moulds in Switzerland (28). In this cross-sectional study, we provide preliminary arguments indicating for the first time that buildings specifically designed to save energy when equipped with improved thermal insulation and controlled mechanical ventilation with heat recovery may further offer the advantage of minimizing mite allergen accumulation and presumably mite growth. These data are important for clinical management since conventional eviction measures are difficult to establish, and have not brought the proof of principle of their efficiency in several studies (11, 12). Nonetheless, in optimal conditions, significant effects on pulmonary function tests in asthmatic patients and on symptoms of allergic rhinoconjunctivitis have been demonstrated (18). The possibility to lower even further mite allergen levels in the home environment by profoundly modifying the growth conditions of mites adds another weapon to this difficult struggle. Optimal ventilation conditions as established in LEB, indeed led to an indoor humidity level 10% lower than in CB where higher numbers of condensation areas and mould growth were observed. Condensation and mould growth in buildings depend on the local relative humidity on surfaces where they develop. The local relative humidity itself depends on indoor air absolute humidity and local surface temperature. In a given (cold) climate, the indoor air absolute humidity depends on indoor sources of water vapour and ventilation rate, while local surface temperature results from indoor temperature and thermal insulation. Therefore, a poorly insulated building or poorly ventilated environment (such as in the CB group) is more at risk of developing local mould growth, and potentially mite growth, than a well-insulated, mechanically ventilated LEB. Although we did not monitor ventilation rates in the studied buildings, the designed ventilation rates in LEB varied from 0.5 up to 1.6 l/(s·m²) floor area. No data was available for CB, since they were naturally ventilated. It is important to note in this regard that in terms of perception of indoor environment, the inhabitants from LEB scored air quality, temperature in winter and perceived overall comfort better than inhabitants from CB did. Modern concepts in architecture and quality of life in the indoor environment impose respect of minimal levels in ventilation, usually superior to those often observed in buildings

of the category of high energy users, where ventilation is not controlled. Heat being thus efficiently recovered from exhaust air and released to fresh air, this ensures good airing at very low energy use. Applying these concepts to the five LEB studied in this paper, our data are contrasting with previous studies, which measured enhanced mite growth when attempting to improve energy consumption by decreasing building ventilation (1, 2).

The major mite allergen Der f 1 level measured in CB, in many instances above 1 µg/g of dust (42% of CB vs 9% of LEB, data not shown) clearly creates conditions of potential sensitization for young children in particular (29, 30). This trend was even more pronounced when Der f 1, Der p 1 and MG2 allergens were cumulated. The nonlongitudinal design of the study, its size and expected low statistical power for these parameters did not allow a valid epidemiological evaluation of allergy expression in the two types of buildings. Indeed, we did not show a relationship between the type of building and the frequency of inhabitants with allergy suggestive signs and symptoms. Nonetheless, the highest levels of mite allergens were measured in apartments of inhabitants with allergy suggestive signs and symptoms, independently of the type of building they were occupying, highlighting the clinical relevance of our data. Because of the homogeneity of the population in the selected area (Lausanne, Switzerland), it is improbable that responses to the health questionnaire might have been influenced by cultural or socio-economical differences.

The level of allergen Der f 1 was the major contributor to the difference observed in cumulative mite allergen level measured in LEB and CB. This difference in the levels of Der f 1 and Der p 1 major allergens appears to be mainly because of regional differences in growth rate and conditions (27), in part related to climate, as demonstrated in other areas in Europe (31), and comparable to current mite distribution observed in neighbouring Italy for instance (32). Moreover, the growth of *Dermatophagoides pteronyssinus* appears particularly sensitive to cold winters, in contrast to *Dermatophagoides farinae*, further contributing to the difference observed (31, 33). In these conditions, it was difficult to expect significant differences between building groups in the level of Der p 1 or MG2 allergens, already low both in CB and LEB, although a trend toward lower Der p 1 and MG2 allergen concentration was present (Fig. 1). Furthermore, our data suggest that continuous low relative humidity in LEB, in contrast to CB, may durably influence microenvironments of housing such as mattresses or carpets. Indeed, in CB-type of environment, microclimates in carpets and bedding have been shown to be very different from room conditions and may not be efficiently influenced by rapidly changing conditions in indoor humidity and temperature (34). However, recent field data and transfer model integrating building design, building content and occupant behaviour provided in contrast evidences that microclimates may be better controlled in stable

environmental conditions (35). Influences of LEB-type of environment on indoor mite favourable microclimates in carpets and bedding will have to be examined in future longitudinal studies. Cat and cockroach allergens used as controls were present at similar levels in CB and LEB. As described in previous studies, cat allergens are community allergens and are easily transported from home to home (30). Cockroaches are not a highly prevalent allergen in Switzerland as reflected by the low titres measured, in contrast to areas such as US inner cities (36). The fact that both cat and cockroach allergens were found in comparable amounts in CB and LEB is a further argument against a confounding factor such as dwellers' cleaning habits to explain the difference in mite levels. Moreover, in this respect, we did not find differences in total amount of dust collected in the two groups of buildings.

Taken together, this study is the first to strongly suggest that novel concepts in building construction aiming to save heating energy may provide conditions able to reduce *D. farinae* mite growth to levels up to 10-fold those found in CB. Remarkably, this difference was quite significant, whereas the energy consumption of LEB was not as low as current optimal energy saving conditions (Swiss Minergie label, 42 kWh/m² of annual total energy use). This study has certainly limitations and data should be considered as preliminary to more extensive, prospective, long-term studies in larger groups of

apartments and buildings. Indeed, because we only considered in this study a single time-point for allergen level measurement and physical parameter registration, it is expected that the complex relationship between energy use, indoor temperature, humidity conditions and mite concentration and growth will have to be further examined in longitudinal studies, including prospective evaluation of allergic patients' health status on the long run. Nonetheless, these preliminary results suggest that a mite-allergic patient living in an apartment in a low-energy building might benefit from mechanical ventilation that reduces relative humidity.

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