

Reducing relative humidity is a practical way to control dust mites and their allergens in homes in temperate climates

Larry G. Arlian, PhD, Jacqueline S. Neal, BS, Marjorie S. Morgan, PhD, DiAnn L. Vyszanski-Moher, MS, Christine M. Rapp, MS, and Andrea K. Alexander, BS
Dayton, Ohio

Background: Maintaining a relative humidity (RH) of less than 50% is one recommendation for reducing numbers of house dust mites and their allergens in homes.

Objective: The purpose of this study was to determine whether, in a humid temperate climate, indoor RH could be sufficiently lowered to control dust mites and their allergens.

Methods: During a period spanning 2 humid summers (May 1998 to October 1999), dust mite and allergen densities were determined in 3 groups of homes. One group (low RH group, n = 23) maintained an RH of less than 51%. Most of these homes used a high-efficiency dehumidifier and air conditioning. A second group of homes (group A) used air conditioning only (n = 19) or air conditioning and dehumidification (n = 5) but did not maintain an RH of less than 51%. A third group of homes (group C, n = 24) controlled climate by opening windows and had an RH of greater than 51%. Normal housecleaning was maintained in all homes during the study.

Results: The low RH group homes started in June with a mean \pm SE of 401 ± 124 live mites and 17 ± 3 μ g of total Der 1 allergen per gram of dust. After 17 months of maintaining an RH of less than 51%, these declined significantly to 8 ± 3 live mites per gram ($P = .004$) and 4 ± 1 μ g of Der 1 per gram of dust ($P < .001$). In contrast, group A and C homes exhibited seasonal peaks of 500 to 1000 mites and 40 to 70 μ g of Der 1 per gram of dust. At all time points after the baseline sample, the low RH group homes had significantly less ($P < .001$) allergen than the group A and C homes. After 17 months, allergen levels were more than 10 times lower in low RH homes compared with humid homes.

Conclusion: This study showed that it is practical to maintain an indoor RH of less than 51% during the humid summer season in a temperate climate, and this resulted in significant reductions in mite and allergen levels. (*J Allergy Clin Immunol* 2001;107:99-104.)

Key words: House dust mites, relative humidity, dehumidification, allergen, Der p 1, Der f 1, *Dermatophagoides species*

Relative humidity (RH) in the ambient environment is the key factor that influences the prevalence of the house dust mites *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus*.¹ These mites live in environments

Abbreviation used
RH: Relative humidity

where there is no liquid water to drink. Instead, they are able to extract sufficient water from their environment if the RH is high enough.

The lowest RH at which water balance can be maintained (critical humidity) for *D farinae* is temperature dependent and ranges from 55% to 73% for temperatures between 15°C and 35°C.² Mites gradually dehydrate and die when continuously exposed to prolonged periods of RH below the critical humidity level. Clustering of mites or exposure to brief periods of moist air daily extends survival of individuals and lengthens the life cycle.³⁻⁷ Laboratory studies show that isolated adult male and female *D farinae* and *D pteronyssinus* mites die in 5 to 11 days when continuously exposed to 40% RH at 25°C to 34°C.^{8,9} Surveys in temperate climates show that mite prevalence fluctuates in parallel with seasonal fluctuations in indoor RH.¹⁰⁻¹⁴ Mites are absent or their densities are low in homes in dry climates unless use of evaporative coolers adds the moisture to the air that is necessary for their survival.¹⁵ Maintaining average daily indoor RH below 50%, even when RH rises above 50% for 2 to 6 hours daily, prevents mite population growth and thus the production of allergen.¹⁶ Therefore maintaining the RH below 50% is one recommendation for reducing dust mites and their allergens in homes.

Several studies show that use of dehumidification in a single room results in lower allergen levels; however, others have shown no benefit from dehumidification.¹⁷⁻²⁴ Many of these studies were limited in that they involved reducing the RH in only one room by using a portable low capacity/efficiency dehumidifier, or they used mechanical ventilation heat pump recovery systems (exchanged dry outside air for moist inside air) not specifically designed to remove moisture from air. Therefore in spite of all the studies that show that RH is critical to mite survival, the recommendation to maintain low RH has not been tested adequately in homes nor have its effectiveness and practicality been demonstrated. The purpose of this study was to determine whether, in a temperate climate, indoor RH could be sufficiently lowered by using high-efficiency dehumidifiers and air conditioning to control dust mites and lower allergens in the dust in homes.

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Reprint requests: Larry G. Arlian, PhD, Department of Biological Sciences, Wright State University, Dayton, OH 45435.

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TABLE I. House characteristics for individual participants in each experimental group

	Low RH (<51%, n = 23)	Group A (>51%, n = 24)	Group C (>51%, n = 24)	Total (n = 71)
Age of house (y)				
0-10	3	3	3	9
11-24	2	7	1	10
≥25	18	14	20	52
Exterior surface				
Brick	12	12	8	32
Siding*	6	6	12	24
Brick or stone/siding*	5	6	4	15
Style				
One story	17	10	7	34
Two story	4	11	15	30
Split-level	2	3	2	7
Basement	7	7	10	24
Crawlspace	0	3	6	9
Slab	16	14	8	38
Heating				
Forced air	21	24	19	64
Radiant	2	0	5	7
Flooring†				
Plush	31	26	28	85
Berber	6	9	5	20
Loop	3	3	5	11
Shag	1	2	1	4
Area rug	4	3	3	10
Hardwood	1	5	6	12
Pets				
Yes	12	16	21	49
No	11	8	3	22

*Siding includes vinyl, aluminum, wood, or stucco.

†Two floors (living room floor and bedroom floor) were sampled in each home (n = 142).

METHODS

The study protocol and informed consent form were reviewed and approved by the Institutional Review Board at Wright State University. All participants provided informed consent and data on age, style, and construction of their house, as well as their types of heating, carpet, and furniture upholstery fabric (Table I). The study was conducted from May 1998 through October 1999 in homes in the Dayton, Ohio, area.

Study groups

The study began with a 1- to 3-week baseline screening period (May 1998) to determine mite densities in homes to qualify individual participants or homes. Seventy-one homes with sufficient mite levels (>100 mites per gram of dust in at least one of 3 sampled locations) in the spring, indicating that mite populations could develop during the warm summer months, were initially selected for the study. The homes were assigned to one of 3 study groups on the basis of the presence or absence of air conditioning and the type of indoor climatic control that each would use during the study period. Group 1 (n = 19) consisted of homes that used air conditioning and a high-efficiency dehumidifier. The dehumidifiers had humidistats, and the participants were instructed to adjust the dehumidifiers to maintain an ambient RH of below 50%. Each home was supplied with a digital hygrometer (Fisher Scientific, Pittsburgh, Pa) so that the participants could monitor their ambient RH and adjust the unit's setting if needed. Group 2 homes (n = 26) used only air conditioning to control indoor climate. Both Group 1 and 2 participants had agreed to keep windows closed to prevent ventilation from

humid outside air. Group 3 homes (n = 26) did not have air conditioning or a dehumidifier, and their indoor climate was controlled with window ventilation as desired. All participants were instructed to follow their regular housekeeping procedures.

The dehumidifiers used in this study (Therma-Stor Products, Madison, Wis) had capacities of 100 pints of water per day at 27°C (80°F) and 60% RH when running constantly. In most homes the dehumidifiers were freestanding in a central location, but in several homes the participants ducted them into their heating, ventilating, and air-conditioning systems.

RH and temperature monitoring

Two temperature and RH HOBO monitors (Onset Computer Corp, Pocasset, Mass) that were programmed to record conditions every 16 or 48 minutes were placed in each participant's home. One monitor was placed on the floor surface that had the highest mite density, except in one home. In that one home, the monitor was placed in the couch, which was the high mite density site. Another monitor was placed on a shelf or table (1-2 m above the floor) in the same room. To gather regional climatic data, HOBOS were placed outside at 2 of the homes. During each home visit, the data on the HOBOS were downloaded, and the monitors were relaunched. Data were analyzed by using Microsoft Excel.

Dust sampling and analysis

Dust samples were obtained by using a portable vacuum cleaner from 3 major mite foci: couch or chair; living room floor next to the couch or chair; and bedroom floor next to the bed. One square yard

of surface area from each sampling site was vacuumed for 2 minutes, and samples were processed as previously described.^{13,25} Dust samples were obtained from all homes at the beginning of the study to establish the baseline. Then samples were collected approximately every 4 to 6 weeks during the warm humid summer months (May-September) and every 8 to 12 weeks during the heating season (October-April). The same areas were vacuumed at each visit. The numbers of live and dead mites were determined in each sample by using a stereomicroscope.

After analyzing each sample for live and dead mites, an aliquot of fine dust was removed and stored at -20°C until analyzed for allergen. The allergen concentrations were determined on all of the stored samples for the first 6 visits at the end of the first year and for the remaining samples at the end of the study. The concentration of Der f 1 and Der p 1 allergens in the samples were determined according to the manufacturer's instructions by using ELISA kits obtained from Indoor Biotechnologies (Charlottesville, Va).

Data analysis

Some homes with dehumidifiers did not maintain ambient RH below 51% ($n = 5$). Conversely, some air conditioned only ($n = 7$) and control ($n = 2$) homes had an RH that were below 51%. Therefore for the purposes of data analysis, homes were assigned to one of 3 groups on the basis of their average ambient RH from June through September 1998. The 3 groups were as follows: (1) the low RH group ($<51\%$, $n = 23$) consisted of all homes with an average ambient RH of $<51\%$ (regardless of climate control); (2) group A ($>51\%$ RH, $n = 24$) consisted of all homes with air conditioning (with or without dehumidifier) with an average ambient RH of greater than 51%; and (3) group C ($>51\%$ RH, $n = 24$) consisted of control homes (no air conditioning or dehumidifier) with an average RH of greater than 51%. The mean for each group was derived from the mean for the 3 samples in each house. There were no significant differences ($P > .05$) in mean live mite and allergen densities among the 3 groups at the start of the study.

Data are given as means \pm SEs. To determine whether there were differences regarding the live mite or allergen densities over time among the 3 groups, a 2-factor univariate ANOVA (group and time) model with a repeated-measures design was used. A 1-way ANOVA was used to examine between- or within-group differences at each time point separately. If the ANOVA indicated that there was a significant difference among the 3 groups, then a Tukey multiple comparison test was conducted to determine where the significant differences were. A paired t test was used to determine significant changes from baseline in mite and allergen densities at specific times for the low RH group.

RESULTS

RH and temperature

Outdoor. Monthly average outdoor temperature ranged from 20.5°C to 25.9°C during the summer months (June-September; Fig 1, A) of both summers but had large daily day-night fluctuations. Monthly average outdoor RH was 73.3% (range, 62.0%-80.7%) during June through September of 1998 and 63.5% (range, 51.6%-70.4%) for the same months in 1999 (Fig 1, B). From October through May, the mean monthly outdoor RH was 64.8% (range, 59.9%-71.4%).

Indoor. Monthly average indoor ambient temperature ranged from 22.2°C to 25.3°C for all the experimental groups during the summer months (June-September of 1998 and 1999; Fig 1, A), with small daily fluctuations that were much greater in non-air-conditioned homes

compared with the air-conditioned homes. Average temperature on the floor surface in all homes was 1.3°C to 1.9°C less than the average indoor ambient temperature during the 2 summers of the study. Average indoor ambient temperature was 3°C to 5°C less during the heating season (range, 19.6°C - 22.8°C) compared with that during the cooling period.

Average indoor ambient RH for the low RH group (ambient RH $<51\%$ from June-September 1998) was 45.9% (range, 37.3%-50.9%) and 45.5% (range, 35.3%-56.3%) for the summers of 1998 and 1999, respectively (Fig 1, B). These homes maintained an essentially constant RH for both summers that were 27.3% and 18.0% less than outdoor conditions for the first and second summers, respectively.

Group A and C homes (ambient RH $>51\%$) had a mean seasonal RH that was between those of the outdoor RH and the low RH group (Fig 1, B). Group C (mostly window ventilated homes) had a higher summer RH than the air-conditioned homes (group A). Group A's average ambient RH for the summer months was 58.5% (range, 51.2%-68.2%) and 55.0% (range, 43.5%-64.9%) for the first and second summers, respectively. Monthly average ambient RH for group C homes was 63.1% (range, 53.2%-72.0%) and 56.8% (range, 46.8%-74.4%) for the first and second summers, respectively. The average ambient RH for the low RH group was 9.5% to 16.5% lower than those of groups A and C for the 2 summer periods (June-September 1998 and June-September 1999). Floor surface RH during the summer seasons was 4.5% to 5.8% above the ambient RH for all homes regardless of group. During December through April, the average indoor ambient RH was less than 48% for all the groups.

Live and dead mite densities

There was a significant difference ($P \leq .0001$) in the pattern of live mite density over time between the low RH homes and groups A and C. In the homes that maintained an ambient RH of less than 51% (low RH group), the average live mite count was 401.2 ± 124.0 mites per gram of dust at the beginning of the study, and then it declined significantly ($P = .004$) to 8.2 ± 2.6 mites per gram by the end of the first heating season (March 1999) and 6.7 ± 1.7 mites per gram at the end of the study in October 1999 (Fig 2, A). In contrast, the densities of live mites in the homes of groups A and C increased in parallel with the summer increases in indoor ambient RH during both summers and then decreased in the late summer and fall as indoor ambient RH decreased (Fig 2, A). In these homes mite densities peaked at an average of 997.8 ± 173.7 and 572.2 ± 189.1 mites per gram during the first and second summer season, respectively, for group C homes. Group A mite levels peaked at an average of 673.8 ± 174.1 and 494.3 ± 154.4 mites per gram for the first and second summers, respectively (Fig 2, A). Mite levels declined in all homes during the heating season in parallel with the decline in indoor ambient RH to levels below the critical humidity necessary for the survival of mites (Figs 1, B, and 2, A). However, when average live

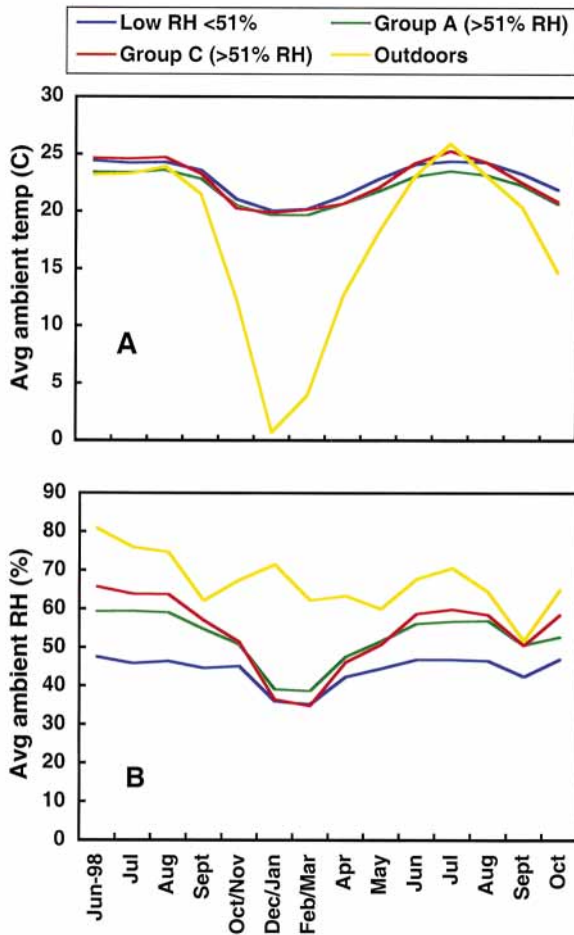


FIG 1. A, Monthly average temperature (in degrees Celsius) in homes for the 3 experimental groups and outdoors. B, Monthly average RH (%) in homes for the 3 experimental groups and outdoors.

mite counts were lowest during the heating season, groups A and C had 28.1 ± 6.8 and 23.1 ± 8.3 mites per gram, respectively, which were 2.8 and 3.4 times higher than the 8.2 ± 2.7 mites per gram found in the low RH group. Profiles for average mite levels for the individual sites (living room floor, bedroom floor, and couch or chair) paralleled the mean for all 3 sites (data not shown). All individual homes that maintained an RH of less than 51% had live mite densities of less than 27 mites per gram of dust by the end of the study (data not shown).

In the low RH group homes, reservoirs of dead mites gradually declined in parallel with live mite density during the 17-month study. Likewise, dead mite densities in the high humidity homes (groups A and C) paralleled live mite densities (Fig 2, B).

Group 1 allergen density

There was a significant difference ($P \leq .0001$) in the time pattern of allergen density between the low RH group and group A and C homes. The mean concentrations of Der 1 (Der f 1 and Der p 1) for the 3 sampled sites signif-

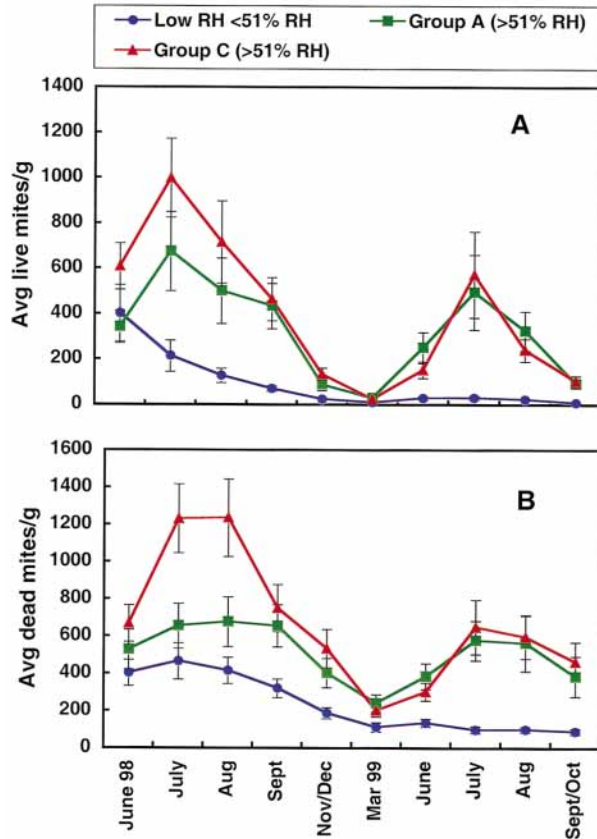


FIG 2. Average number (living room floor, bedroom floor, and couch-chair) of live (A) and dead (B) mites per gram of dust in homes that maintained an RH of less than 51% and 2 groups of homes that had an RH of greater than 51%.

icantly decreased ($P < .001$) in the low RH group homes from $17.5 \pm 3.2 \mu\text{g/g}$ dust at the beginning of the study to $3.8 \pm 0.7 \mu\text{g/g}$ dust at the end of the study (Fig 3). In contrast, mean Der 1 concentrations in group A and C homes showed similar trends to those seen for the live mite counts and increased during the humid summer months then decreased during the dry winter months. Mean allergen concentrations for the individual sites paralleled the combined mean allergen concentrations for all 3 sites. At the end of the study, allergen density was significantly lower ($P < .001$) in the homes with an RH of less than 51% ($3.8 \pm 0.7 \mu\text{g/g}$) compared with the 2 groups with an RH of greater than 51% (48.9 ± 19.0 and $45.5 \pm 15.8 \mu\text{g/g}$).

Most homes had more Der f 1 allergen than Der p 1 allergen, indicating that *D. farinae* was the dominant species in these homes. This is important because this species is better adapted for living in dryer climates.

DISCUSSION

In temperate climates, such as southwest Ohio,^{13,25} mite levels fluctuate sharply in parallel with seasonal fluctuations in indoor RH. Large amounts of allergen are produced and accumulate in carpets, sofas, and mattresses during the time when mite populations flourish, and

much of this allergen remains in these substrates during the heating season.

Our current study was initiated in the spring, when live mite density is low and seasonal indoor and outdoor RH in southwest Ohio typically begins to increase and a parallel increase in dust mite population density occurs. Participants in 14 of 19 homes who used a dehumidifier and air conditioner maintained an ambient RH of less than 51% during the summer months. Seven of 26 participants that used air conditioning only also maintained an indoor RH of less than 51%. In addition, 2 of 26 window-ventilated homes also maintained an average RH of less than 51%, even though the mean daily outdoor RH was high (>65%). The RH in the remaining homes was above 51% during the summer months.

The mean indoor RH in homes with reduced humidity (low RH group) was 18% to 27% below the outdoor RH during both summers. These low RH levels prevented mite populations from developing in these homes during the summer mite season and in fact resulted in an almost complete elimination of live mites in the sampled sites. More importantly, the elimination of most live mites (the breeding population) coupled with normal housekeeping resulted in a 76.5% overall reduction in allergen densities 17 months after initiation of the study (from 17 to 4 $\mu\text{g/g}$ of dust). Even after maintaining a low RH for only one summer, the mean allergen level at the end of the first heating season had declined by 65% to 6 $\mu\text{g/g}$ of dust in the low RH group homes, which was significantly ($P < .001$) less than in the other homes that did not maintain an RH of less than 51% but had continued normal housecleaning. The decline in allergen levels was exponential, with a regression coefficient of -0.023 ($R^2 = 0.9713$). Projecting forward by using this regression coefficient, the average allergen concentration in the dust would have been less than 2 $\mu\text{g/g}$ had the study continued for another 6 months or through the second heating season. Thus simply by reducing indoor RH to less than 51% for 2 consecutive summers, coupled with normal cleaning and no other intervention, mite allergen densities in these homes were reduced to levels that likely were not clinically significant for most allergic patients.

The homes in this study that did not maintain an RH of less than 51% exhibited the typical large mite population explosions and concomitant dramatic increases in allergen levels during the summer months. Most homes that used air conditioners without dehumidifiers (19/26) did not maintain an RH of less than 51%. It is not clear why 7 air-conditioned homes without dehumidifiers were able to maintain an RH below 51%. We theorize that the air-conditioning systems in these homes had lower cooling efficiencies and operated frequently and for longer duration, thus acting as dehumidifiers. Regardless, although strict use of air conditioning by itself prevented the development of the typical seasonal large mite populations in some homes, in most homes the use of air conditioners without dehumidifiers provided no benefits.

The living areas of the homes that were dehumidified ranged from about 800 to 2800 square feet of living

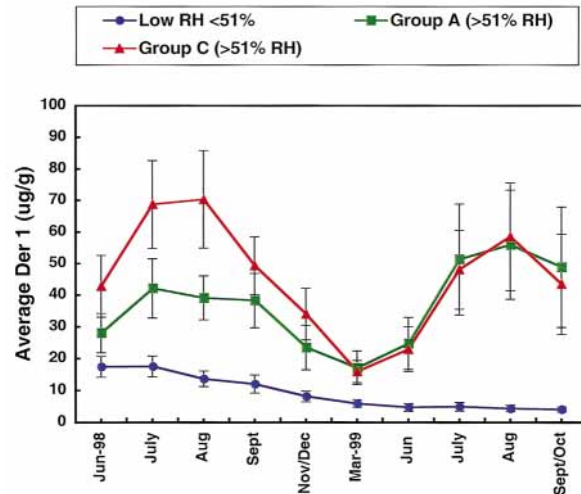


FIG 3. Average concentration (3 sites) of Der 1 (Der f 1 plus Der p 1) per gram of dust (living room floor, bedroom floor, and couch-chair) in homes that maintained an RH of less than 51% and 2 groups of homes that had an RH of greater than 51%.

space. Homes of the other 2 groups were of similar size. Each group contained homes of similar physical characteristics and construction (Table I). Therefore the general physical-structural characteristics of the homes in each group were relatively similar.

It is difficult to measure the exposure to airborne mite allergen and to relate this to the densities of mites and allergen in carpet or upholstered furniture. Mite allergen becomes airborne during disturbances.²⁶⁻³² It is logical to conclude that significantly reducing live mite levels (breeding populations), coupled with regular thorough cleaning of carpets and sofas, will ultimately reduce total mite and allergen densities in the surface dust and, subsequently, the amount in the air during disturbances. Thus this should reduce allergen exposure. Our study showed that once mites were killed, the amount of allergen that was recovered from the surface of carpets and sofas at each sampling time diminished as a result of the participants continuing their regular vacuum cleaning. Presumably, there must be a parallel reduction in the amount that becomes airborne during disturbances and thus a reduction in exposure by inhalation.

The major breeding locations for dust mites in homes are mattresses, carpets, and fabric upholstered furniture. Use of mattress and pillow encasements, coupled with frequent laundering of bedding, practically eliminates mite allergen exposure from beds. Presently there are few non-chemical methods available for controlling dust mites in carpets and upholstered furniture. There is also the issue of safety when using chemicals. It has been recommended that carpets be replaced with hard floor covering (eg, vinyl or wood) and that fabric-covered furniture be replaced with hard furniture (eg, wood or plastic) or with furniture with nonporous covers (eg, leather or vinyl). However, carpets and fabric-upholstered furniture are preferred in

US homes, and individuals are reluctant to remove them. Therefore reducing RH may be an alternative solution to removal of carpets and fabric-covered furniture in many homes in temperate climates. Reducing the RH in the whole house should also kill mites in mattresses and bedding as well and prevent colonization of these breeding sites. Although we did not monitor mite and allergen levels in mattresses and bedding, the lack of mites and allergen in mattresses and bedding in dry climates, such as the Rocky Mountain States, supports this hypothesis.

In conclusion, our study showed that it is possible, practical, and effective to reduce indoor RH to levels that will control dust mite populations in most homes in temperate climates. Use of free-standing high-efficiency dehumidifiers and air conditioning in typical houses in a temperate climate decreased indoor RH during the summer mite season to levels that prevented mite populations from developing. This, coupled with regular vacuum cleaning by the participants of the study, resulted in the reduction of allergen in dust to insignificant levels for most patients. In temperate climates patients with dust mite sensitivity may wish to consider a plan to control mites through humidity modification. Whether use of dehumidifiers to reduce mites is possible in subtropical climates, such as in the southern United States, remains to be determined.

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