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# Pollen and fungal spores indoor and outdoor of mobile homes

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**Background:** Allergenic diseases triggered by aeroallergens extract a health cost in quality of life and in economic impact. People generally spend 90% to 95% of their time indoors, so understanding the environmental factors that affect the presence of aeroallergens indoors are important in understanding health impact and potential intervention methods.

**Objective:** Describe the relationship of indoor airborne pollen and fungal spores in occupied mobile homes with outdoor concentrations and other environmental factors within geographically diverse areas of Texas.

**Methods:** Airborne pollen and fungal spores were collected during the daytime with RotoRod samplers indoor and outdoor of mobile homes in Houston and El Paso, Texas. Samples were counted simultaneously with a dual eyepiece microscope and identified morphologically and through staining techniques.

**Results:** Geometric mean concentrations (counts/m<sup>3</sup>) indoors and outdoors for pollen, respectively, were Houston 7.1 and 196.4; and El Paso 17.5 and 71.5. Geometric mean concentrations (counts/m<sup>3</sup>) indoors and outdoors for spore, respectively, were Houston 98.5 and 196.4; and El Paso 36.9 and 71.5. Indoor to outdoor ratios (I/O) for pollen and fungal spores were found to be higher on average than has been previously reported. Modeling of predictive factors in Houston demonstrate that 62% and 41% of indoor levels of pollen and fungal spores, respectively, can be explained by their corresponding outdoor levels. These data suggest that the many factors associated with individual exposure to airborne pollen and fungal spores indoors are under the control of the occupant, and may additionally be influenced by the physical characteristics of mobile homes, in particular the high surface area to volume ratio and restricted flow patterns.

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## INTRODUCTION

The relationship of indoor concentrations of airborne pollen and fungal spores in occupied mobile homes in Texas to outdoor levels and other environmental factors was investigated. The data source described is from the "Texas Indoor Air Quality Study,"<sup>1</sup> a multidisciplinary investigation of the association between human health and formaldehyde of occupants in manufactured housing (mobile homes). The

study encompassed indoor and outdoor environmental sampling for a number of variables. These variables included indoor and outdoor airborne pollen and fungal spores, temperature, and relative humidity.<sup>2–4</sup>

Bioaerosols such as pollen and fungal spores are commonly considered aeroallergens, and are associated with hayfever, rhinitis, and asthma in children and adults, and as potential infection agents and carriers.<sup>5–8</sup> Allergenic diseases, which are triggered by aeroallergens, extract a health cost in quality of life and in economic impact. Asthma is the leading cause of morbidity in childhood<sup>9</sup> and exposure to environmental allergens may play a significant role in asthma related mortality.<sup>10–12</sup> Allergens may also interact with other airborne contaminants

such as ozone and respirable particulate matter and may influence severity of asthma outcome.<sup>13</sup> People generally spend 90% to 95% of their time indoors, so understanding the environmental factors which effect the presence of aeroallergens indoors is important in assessment of health impact and development intervention methods.

Mobile homes differ from traditional homes in construction methods and materials. These differences have been well characterized as to their impact on indoor air quality to formaldehyde from building materials, infiltration and air exchange rates from construction methods.<sup>2,14–16</sup> Although a number of studies have reported on factors that influence airborne allergens in traditional homes, no studies have dealt with indoor aeroallergens in mobile homes or other factors such as demographic and behavior patterns.

The ambient environment has been shown to be the major source of indoor pollen and fungal spores, and the specific types are dependent on geographic location, season, and climate.

Aeroallergens enter a home through infiltration, open windows and doors, and can be carried in by occupants and pets. These modes of entry are influenced by the physical characteristics of the structure, presence, and type of air control systems; air exchange rates and maintenance; and behavior patterns of occupants.<sup>17–19</sup> The micro environment of the home is also important in secondary growth and release of aeroallergens which differ in type and concentration from those found outdoors due to control of indoor temperature and humidity,<sup>20,21</sup> and presence of growth source materials, such as organic buildup in ventilation systems and wall condensation.<sup>5,22</sup>

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## METHODS

Field sampling for airborne pollen and fungal spores was performed from October, 1982 through May, 1983 in mobile homes in four distinct geographic and climatic regions of Texas. The primary purpose of the study was to assess human exposure to formaldehyde. The data set was not analyzed to evaluate aeroallergens in these mobile homes. The results presented in this report consist of the aeroallergen data that were collected from two diverse regions in Texas: 41 homes in Houston during the winter and fall, and 40 homes in El Paso during the fall. Outdoor pollen and fungal spores exhibit seasonal variations and the possibility of finding highly variable indoor air quality exists. In order to test for these variations repeat measurements were made during the summer months in 25 of the homes in El Paso, and 10 homes in Houston. All homes were not re-sampled due to factors such as the inherent mobility of the population and summer vacations.

Sampling regions were randomly selected within each city and individual homes recruited through door-to-door canvassing. Indoor measurements were obtained during the day time (8 AM to 5 PM) in the main living area of all homes. On each sampling day airborne pollen and fungal spore samples were collected simultaneously outside one of the study homes. Samples were

collected one meter above the floor or ground which emulates the breathing zone height of a child. Temperature and relative humidity measurements were obtained indoor and outdoor at all sites.<sup>1</sup>

Aeroallergens were collected with the RotoRod sampler.<sup>23</sup> The RotoRod sampler is not affected by wind speed, direction, and orientation. The sampling efficiency of the RotoRod is highest for particles  $\geq 10 \mu\text{m}$  in aerodynamic diameter.<sup>24</sup> This comprises the size ranges of pollen and fungal spores that are predominant as ambient aeroallergens.<sup>25,26</sup> Integrated air samples were collected over the sample time period through automatic setting and operation of the RotoRod samplers. The sampling time duty cycle was varied to sample a sufficient quantity of air for reliable counts while simultaneously limiting over sampling. Oversampling typically results in the collection of too much dust to accurately count and identify the collected pollen and spores. Pollen and fungal spores were identified and counted simultaneously by two microbiologist technicians with a dual eyepiece microscope. Identification was made morphologically and through differential staining techniques.

All data are transformed to log normal (ln) values to stabilize the variability of environmental measurement distributions. Statistical analyses are

performed using SPSS release 7.5. Average values for all transformed data are reported as geometric means.

## RESULTS AND DISCUSSION

### Indoor/Outdoor Relationships

The summary of the results for airborne pollen and fungal spores is presented in Tables 1 and 2, respectively. The geometric means (GM) and geometric standard deviations (GSD) of the indoor and outdoor concentrations, sample size, and geometric means of the paired indoor to outdoor ratios (I/O) are reported, and are stratified by season of sampling. The paired sample results include only those samples in which simultaneous indoor and outdoor aeroallergens were collected at the same location.

The sampling period in Houston was spread over three seasons: winter, spring and summer. The results obtained outdoors during the summer for airborne pollen and fungal spore concentrations are consistent with previous daytime measurements, using the same collection methods, outdoor of traditional one-family homes in the Houston area reported by Stock and Morandi.<sup>5</sup> Geometric mean counts/m<sup>3</sup> for outdoor pollen of 10.5 to 18.5, and for outdoor spore of 566.8 to 862.6 were reported, and are similar to the results reported here. This suggests good reproducibility of the sampling techniques, potential to generalize

Table 1. Summary of Airborne Pollen Measurements (counts/m<sup>3</sup>) for Houston and El Paso

| City         | Indoor*<br>GM† | GSD‡       | N         | Outdoor*<br>GM | GSD        | N         | GM I/O§     | N         |
|--------------|----------------|------------|-----------|----------------|------------|-----------|-------------|-----------|
| All          | 13.1           | 3.4        | 68        | 21.0           | 3.6        | 39        | 0.53        | 26        |
| Houston      |                |            |           |                |            |           |             |           |
| Winter       | 2.3            | 4.6        | 6         | 4.9            | 2.5        | 7         | 0.43        | 2         |
| Spring       | 8.3            | 2.3        | 7         | 21.5           | 1.8        | 4         | 0.37        | 4         |
| Summer       | 13.3           | 1.9        | 9         | 20.1           | 1.8        | 8         | 0.91        | 4         |
| <b>Total</b> | <b>7.1</b>     | <b>3.4</b> | <b>22</b> | <b>12.1</b>    | <b>2.7</b> | <b>19</b> | <b>0.55</b> | <b>10</b> |
| El Paso      |                |            |           |                |            |           |             |           |
| Spring       | 26.3           | 2.9        | 27        | 59.7           | 4          | 10        | 0.55        | 7         |
| Summer       | 9.8            | 2.6        | 19        | 20.7           | 3          | 10        | 0.50        | 9         |
| <b>Total</b> | <b>17.5</b>    | <b>3.1</b> | <b>46</b> | <b>35.2</b>    | <b>3.8</b> | <b>20</b> | <b>0.52</b> | <b>16</b> |

\* Indoor and outdoor values are presented as geometric means in the units of count/m<sup>3</sup>.

† Geometric mean.

‡ Geometric standard deviation.

§ Geometric mean of averaged ratios for individually paired indoor/outdoor concentrations.

Table 2. Summary of Airborne Fungal Spore Measurements (counts/m<sup>3</sup>) for Houston and El Paso

| City             | Indoor*<br>GM† | GSD‡ | N  | Outdoor§<br>GM | GSD | N  | GM I/O§ | N  |
|------------------|----------------|------|----|----------------|-----|----|---------|----|
| Combined Houston | 53.4           | 3.8  | 92 | 129.1          | 5.3 | 48 | 0.48    | 36 |
| Winter           | 17.3           | 5.7  | 10 | 45.2           | 4.1 | 14 | 0.45    | 4  |
| Spring           | 122.7          | 2.9  | 10 | 880.1          | 3.6 | 5  | 0.08    | 5  |
| Summer           | 267.7          | 2.8  | 15 | 837.1          | 2.8 | 9  | 0.70    | 9  |
| <b>Total</b>     | 98.5           | 5.4  | 35 | 196.4          | 7.1 | 28 | 0.33    | 18 |
| El Paso          |                |      |    |                |     |    |         |    |
| Spring           | 36.2           | 2.2  | 32 | 85.6           | 2.9 | 10 | 0.44    | 8  |
| Summer           | 37.7           | 2.8  | 25 | 59.7           | 1.9 | 10 | 0.80    | 10 |
| <b>Total</b>     | 36.9           | 2.5  | 57 | 71.5           | 2.5 | 20 | 0.68    | 18 |

\* Indoor and outdoor values are presented as geometric means in the units of count/m<sup>3</sup>.

† Geometric mean.

‡ Geometric standard deviation.

§ Geometric mean of averaged ratios for individually paired indoor/outdoor concentrations.

from this data, and overall consistency of ambient concentrations during these summer months in Houston.

A difference between winter with both spring and summer concentrations for pollen and fungal spores in Houston is shown. Overall indoor concentrations increased from the winter to the spring and increased again in the summer. Indoor pollen increased by a factor of 4.6 from winter to spring, and 1.6 from spring to summer. Indoor fungal spores increased by a factor of 7.1 from winter to spring, and 2.2 from spring to summer. The outdoor pollen and fungal spore concentrations increased by a factor of 4.4 and 19.5, respectively, from winter to spring, but remained unchanged from spring to summer. These changes in indoor and outdoor concentrations' results in an indoor/outdoor (I/O) ratio that decreased from winter to spring, but increased in the summer to approximately 2 times the winter ratio for both pollen and fungal spores. In Houston 98% (40 out of 41) of the mobile homes in the study contained electric window mounted or central air conditioning that was used throughout the majority of the summer months. Although the use of air conditioners has been reported to decrease the I/O ratio in other investigations<sup>27,28</sup> the reverse is demonstrated in these results. The increase of the I/O ratio observed in these data may be an artifact of the

number of outdoor samples available for paired comparison analysis. The I/O ratio for fungal spores, which has a greater number of indoor and outdoor sample pairs than for pollen, also increased during the summer. Further, the ratios of the geometric means for the total indoor and outdoor samples during winter, spring, summer, and the combined total, when compared with the I/O geometric mean for paired values that are shown in Table 3, follow the same pattern and show similar results. In addition, what is observed may be a lag in the infiltration of spring aeroallergens outdoor to the indoors. Previous studies have also shown that collection of fungal spores on air conditioner filters may facilitate

growth of fungi and act as a secondary indoor source of spores,<sup>22</sup> which may be occurring over the spring season. The humid environment of Houston during the summer may facilitate this effect.

The summer sampling in El Paso showed little change in indoor fungal spore concentrations from spring to summer, but an associated decrease in the outdoor concentrations resulted in almost a doubling in the I/O fungal spore ratio. Pollen decreased in similar proportions both indoor and outdoor over the same time period with no real change in the I/O ratio. The higher indoor pollen counts during the spring represent the seasonal variation with more plants blooming in the arid west Texas environment during the spring than summer. High airborne fungal spore levels do not show seasonal relationships and are associated with environmental conditions at that time.<sup>29</sup> The increase in the I/O ratios for fungal spores during the summer may be related to the predominant use of evaporative coolers that may concentrate outdoor spores indoors. Evaporative coolers are used by 93% of the study homes in El Paso. An association between use of evaporative coolers and lower respiratory tract illness in infants was previously reported and the causative factor was hypothesized as related to an increase in indoor fungal counts.<sup>30</sup> Elevated airborne fungal

Table 3. Comparison of Paired Indoor/Outdoor Geometric Mean Ratios With The Ratio of the Separate Indoor and Outdoor Geometric Means For All Measurements in Houston

| Season | Pollen |         | Fungal Spores |         |
|--------|--------|---------|---------------|---------|
|        | Total* | Paired† | Total*        | Paired† |
| Winter | 0.46   | 0.43    | 0.38          | 0.45    |
| Spring | 0.38   | 0.37    | 0.14          | 0.08    |
| Summer | 0.66   | 0.91    | 0.32          | 0.70    |

\* Ratio of the geometric mean of all indoor measurements divided by the geometric mean for all outdoor measurements.

† Geometric mean of averaged ratios for individually paired indoor/outdoor concentrations.

spore levels have also been associated with periods of increased pulmonary complaints, particularly among people with asthma and other at risk individuals.<sup>29</sup>

Specific design and construction characteristics of mobile homes may be a factor in results observed. The design and manufacture of mobile homes are substantially different from one-family, on-site construction of traditional housing. Mobile homes typically have less living space area, are one story, have a crawl space without a surrounding foundation, and have an occupant flow pattern that is restricted through the primary living areas. Although mobile homes typically are of tighter construction resulting in lower infiltration/exfiltration rates than traditional housing, they have a greater surface area to volume ratio. The high surface area to volume ratio may enhance the entry of airborne pollen and fungal spores when windows and doors are open. Indoor temperature remains relatively constant from control by the house occupants of heating and cooling systems. As the temperature difference between indoor and outdoor increases, such as during winter and summer, so do the air infiltration and exchange rates.<sup>22</sup> This effect is demonstrated in Tables 1 and 2 where the I/O ratio in Houston is higher during the extreme temperature periods in both

the winter and summer than in the spring. The limited occupant flow pattern in mobile homes could re-entrain particles in higher concentrations than would occur in traditional homes, and increase the measurable airborne concentrations indoors. During seasons when windows are closed and more time is spent indoors, such as winter and summer in Houston, airborne particles per volume of indoor air will increase. Foot traffic has been shown to increase the airborne concentrations of fungal spores.<sup>31</sup>

#### *Influence of Selected Factors on the Presence of Indoor Aeroallergens*

The influence of outdoor aeroallergen concentrations and indoor and outdoor temperature and relative humidity (rH) relationship with airborne indoor pollen and fungal spore concentrations was investigated. The (ln) indoor concentrations were regressed pairwise against (ln) transformed variables that had plausible relationships, and which were found to be significantly ( $P > .05$ ) correlated with indoor concentrations of airborne pollen or fungal spore concentrations. For example, even though both outdoor pollen and outdoor spore were two of the factors found significantly correlated with indoor pollen in Houston, only outdoor pollen is included in the model, since the presence of outdoor spore would

only be a surrogate measure for outdoor pollen. Tables 4 and 5 summarize the regression parameters for indoor pollen and fungal spore aeroallergens, respectively, in a stepwise fashion. The parameters are entered in order of the strength of their independent correlation's. The tables include the individual models with the stepwise addition of each factor, the corresponding additive predictability ( $R^2$ ) for each factor, and the significance of each regression slope from zero.

In El Paso, even though significant correlations with indoor pollen are found for outdoor pollen (0.60,  $P < .01$ ) and indoor relative humidity ( $-.037$ ,  $P < .05$ ), the variability for either factor was too great for the model to be significant. Temperature and relative humidity, indoor and outdoor, are not correlated with indoor fungal spore concentrations in El Paso for the development of a model.

The regression models for Houston show that up to 67% of the indoor pollen and almost 78% of the indoor fungal spore concentrations can be explained by outdoor pollen concentrations, and temperature and relative humidity. For indoor pollen, the outdoor concentration is the main contributing factor with the indoor temperature explaining only an additional 5.6%, while for indoor fungal spore, even though outdoor levels explain 42%, the

Table 4. Stepwise Regression in Order of Strength of Individual Correlation's Describing Relationship Between Airborne Indoor Pollen Concentrations (counts/m<sup>3</sup>) With Factors Found to be Significant\*

| City     | N  | Model: $\text{LN Conc}_{\text{in}} = \beta_1 (\text{LN of factor}_1) + \beta_2 (\text{LN of factor}_2) + C$ |                    |                            | Significance Level (P) | R <sup>2</sup> , % |
|----------|----|-------------------------------------------------------------------------------------------------------------|--------------------|----------------------------|------------------------|--------------------|
|          |    | $\beta_1$                                                                                                   | $\beta_2$          | C (counts/m <sup>3</sup> ) |                        |                    |
| Houston  |    | Outdoor Pollen                                                                                              | Indoor Temperature |                            |                        |                    |
|          | 10 | 1.091                                                                                                       | —                  | −0.832                     | 0.007                  | 61.7               |
| El Paso  | 10 | 0.828                                                                                                       | 6.025              | −19.688                    | 0.020                  | 67.3               |
|          |    | Outdoor Pollen                                                                                              | Indoor rH          |                            |                        |                    |
|          | 16 | 0.308                                                                                                       | —                  | 1.807                      | 0.205                  | 11.2               |
|          | 16 | 0.230                                                                                                       | −0.768             | 4.873                      | 0.265                  | 18.5               |
| Combined |    | Outdoor Pollen                                                                                              | Indoor rH          |                            |                        |                    |
|          | 26 | 0.587                                                                                                       | —                  | 0.671                      | 0.003                  | 30.7               |
|          | 26 | 0.524                                                                                                       | −0.511             | 2.802                      | 0.011                  | 32.5               |

\* All regressions are performed on the log normal transformed variables.

Table 5. Stepwise Regression in Order of Strength of Individual Correlation's Describing Relationship Between Airborne Indoor Fungal Spore Concentrations (counts/m<sup>3</sup>) With Factors Found to be Significant\*

| Model: $\text{LN Conc}_{\text{in}} = \beta_1 (\text{LN of factor}_1) \cdot \beta_2 (\text{LN of factor}_2) \cdot \beta_3 (\text{LN of factor}_3) \cdot \beta_4 (\text{LN of factor}_4) + C$ |    |                  |                        |               |                       |                               |                           |                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|------------------|------------------------|---------------|-----------------------|-------------------------------|---------------------------|--------------------|
| City                                                                                                                                                                                        | N  | $\beta_1$        | $\beta_2$              | $\beta_3$     | $\beta_4$             | C<br>(counts/m <sup>3</sup> ) | Significance<br>Level (p) | R <sup>2</sup> (%) |
| Houston                                                                                                                                                                                     |    | Outdoor<br>Spore | Outdoor<br>Temperature | Indoor<br>rH  | Indoor<br>Temperature |                               |                           |                    |
|                                                                                                                                                                                             | 18 | 0.426            | —                      | —             | —                     | 2.277                         | 0.004                     | 42.0               |
|                                                                                                                                                                                             | 18 | 0.107            | 1.936                  | —             | —                     | -2.039                        | 0.001                     | 60.3               |
|                                                                                                                                                                                             | 18 | 0.234            | 1.230                  | 4.860         | —                     | -19.984                       | <0.001                    | 77.1               |
|                                                                                                                                                                                             | 18 | 0.253            | 1.447                  | 4.844         | -2.622                | -12.193                       | <0.001                    | 77.8               |
| El Paso†<br>Combined                                                                                                                                                                        |    | Outdoor<br>Spore | Outdoor<br>Temperature | Outdoor<br>rH |                       |                               |                           |                    |
|                                                                                                                                                                                             | 35 | 0.446            | —                      | —             |                       | 2.034                         | <0.001                    | 41.2               |
|                                                                                                                                                                                             | 35 | 0.368            | 0.868                  | —             |                       | -0.406                        | <0.001                    | 46.7               |
|                                                                                                                                                                                             | 35 | 0.302            | 1.145                  | 0.565         |                       | -3.042                        | <0.001                    | 51.3               |

\* All regressions are performed on the log normal transformed variables.

† No significant correlation's were found with indoor or outdoor temperature or relative humidity or outdoor fungal spore concentrations.

addition of outdoor temperature explains an additional 18.3%, indoor relative humidity another 16.8%, and indoor temperature only another 0.7%.

Although a regression model is demonstrated for the combined data for pollen and fungal spores, it is felt that this model is dominated by the significance of the Houston regression factors. It is noteworthy, however, that the secondary regression factor for indoor pollen is indoor rH, and for fungal spore is outdoor rH, neither of which are included within the regression model for Houston.

#### Limitations

Usable samples are not available for all homes due to oversampling. The presence of excess soiling on the sample rods may be indicative of a greater quantity of material in the air at that site, which may include pollen and spores, and may pose a potential bias toward lower counts. Most oversampling results, however, are seen primarily with the first samples obtained in each city for each season, with the duty cycle being adjusted following the initial sample results for the remaining households to reduce oversampling potential. In this situation, loss of samples through oversampling is considered a random event with no effect on interpretation of the data analysis. Aeroallergen data are evalu-

ated for 79% of the sampling visits (92 of the 116 homes): 69% in Houston (35 homes), and 88% in El Paso (57 homes).

As previously described, the study design from which the aeroallergen data are derived was to evaluate formaldehyde levels and human health. Secondary data analysis has potential limitations on interpretation of the results. For example, there may have been causes for differences between outdoor and indoor air that are specifically associated with pollen and fungal spores that were not included in the study design or in the selection of household samples, although randomized for the main study factors, may not be as representative for pollen and fungal spores. The comprehensive nature of the study included measurements for the expected affecting factors. The primary limitation due to the original study design with emphasis on formaldehyde resulted in a less than favorable sample size of paired indoor/outdoor measurements. This limitation was minimized by the favorable comparison between the paired measurements and the combined total measurements shown in Table 3.

#### CONCLUSIONS

Indoor concentrations of airborne pollen and fungal spores are dependent on

a combination of factors that comprise geographic locations and climate, season, and characteristics of the home and occupants. For pollen and spores that predominantly derive from outdoor sources, the ambient concentration is of greatest importance and is dependent on geographic location and seasonal fluctuations. Indoor pollen and fungal spores are directly related to outdoor temperature through direct effects on pollen and fungal spore production; on air exchange and infiltration through pressure differentials; and, indirectly through its effect on the occupant selection of air control systems (heating and cooling). The high surface area to volume ratio and restrictive occupant flow patterns of mobile homes emphasize these effects. In addition there may be demographic factors associated with individuals who select to live in mobile homes, not explored in this work, that may affect health outcomes.

The inability to determine a predominant significant relationship between indoor and outdoor environmental factors for El Paso, or the combined data, implies that depending on the climate and season, an important role is played by occupants and the micro environment of the home. The use of certain air control systems may concentrate outdoor aeroallergens indoors. With-

out proper maintenance, filters and other media may act as a secondary indoor source, with fungi growing on these media and creating spores within the home. Occupant activities involved with movement in and out of the home, which tend to increase in fall and spring, will act to transport pollen and fungal spore particles indoors, re-entrain settled particles back into the air, and effect air exchange rates (opening and closing of doors and windows).

These data suggest that the greatest factors associated with individual exposure to airborne pollen and spore indoors may be under the control of the occupant. Through selection of temperature settings and use of air control systems, opening of windows, and selection of activity patterns, the impacts of outdoor and indoor sources are influenced through changes in air exchange rates, re-entrainment of allergens into the indoor air, and creation of micro-environments favorable to the growth indoors. These factors may additionally be influenced by the physical characteristics of mobile homes, in particular the high surface area to volume ratio and restricted flow patterns. The potential for elevated levels of aeroallergens within mobile homes has implications for asthma-related illness and other upper respiratory related adverse health outcomes triggered or exacerbated by aeroallergens.

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