Author's response to reviews

Title: Control of asthma triggers in indoor air with air cleaners: a modeling analysis

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Author's response to reviews: see over
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Dr. David Ozonoff
Editor, Environmental Health

RE: Manuscript # 1459191990183232 (Mitigation of asthma triggers in indoor air: An inter-comparison of ventilation/filtration options for residences Theodore A Myatt, Taeko Minegishi, Joseph G Allen and David L Maclintosh)

Dear Dr. Ozonoff,

We appreciate the opportunity to potentially publish our manuscript in *Environmental Health*. Attached to this letter are detailed responses to each of the reviewer's questions and concerns. Additionally, we have reviewed the manuscript to ensure that it meets the formatting and style requirements. If additional questions arise regarding our manuscript, please do not hesitate to contact me.

Sincerely,

Ted A. Myatt, Sc.D.
Specific Major Comments:

1. Title: It should be made clear in the Title that this article is a modeling study. This is important considering that the CONTAM software has not been validated for characterizing indoor cat allergens, ETS, fungal spores and virus levels (see pt 2). The present title can be misleading.

   We have revised the title of the study to “Control of asthma triggers in indoor air with air cleaners: a modeling analysis” to acknowledge the fact that the study is a modeling effort.

2. Introduction, P5. 2nd para: In keeping with the above point, it is inaccurate to state “…use a validated indoor air quality modeling system to examine peak and time-integrated concentrations of fungal spores…..”. It implied that the model has been scientifically verified for these asthma triggers. To the best of this Reviewer’s knowledge, the CONTAM software has been validated for VOCs only [1]. It would be more appropriate to state that the software is used to characterize the asthma triggers studied.

   We have removed the word “validated” in the abstract and introduction and included a paragraph detailing the validation studies on CONTAM to date in the methods section. The new text in the method section is below:

   Performance evaluations of CONTAM have demonstrated that the model simulations of inter-zonal flow and air exchange rate are within 15% on average of corresponding values measured in a single-family home and test home, respectively [24-29].

   We also added the following new text to the discussion section:

   Prior performance evaluations of CONTAM demonstrate that the model provides a reasonable degree of accuracy for the types of indoor air quality simulations upon which our analyses rely. Inter-zonal airflow predictions from CONTAM simulations of a single story home were within 15% of corresponding measured values [29]. Similarly, air exchange rates for a single room building predicted with CONTAM were within 5% of measured levels [24]. In a related analysis, the correlation between predicted and observed concentrations of a conservative gas ranged from 0.95 to 0.998 during six tests within a single room test home [25]. In a tracer gas study conducted in a multi-room occupied townhouse, gas concentrations predicted by the model were within 25% of measured concentrations [26]. Finally, measured and predicted 24-hour average concentrations of 0.3 to 5 µm particles in a single room building were within 30% of each other [24].

3. Methods, P8, 1st para: It is interesting to note that the authors had assumed independence of particle deposition rates with AER (citing the works of Thatcher et al.?). Firstly, Thatcher et al (2002) did not report that deposition rates were independent of AERs but that it varies with air velocities. As such, please move the ref [34] to between
“colleagues” and “and”. Secondly, contrary to the authors assumptions, studies have shown that for high AERs (in NV residences), indoor turbulence may be expected to be increased, thus increasing the likelihood that particles will migrate through the boundary layer and deposit onto surfaces [2,3]. Thus the modeled values may be overestimated for scenario N. Please discuss in light of these or change accordingly.

We have removed the erroneous citation. While there are several studies that demonstrate a relationship between deposition rates and AER in real house studies (such as Long et al 2001 and Abt et al 2000), other studies have not been able to demonstrate this relationship (Howard-Reed et al 2003). Regardless, CONTAM does not allow for adjustment of deposition rates based on AER, therefore. We have noted this limitation in the methods section and discussed in the text with the following comments:

Particle deposition has been reported to be positively associated with air exchange rate due to increased turbulence of indoor air [63, 64]. Because of modeling constraints, we assumed that particle deposition rates were independent of air exchange rate. This simplifying assumption is unlikely to be a substantial contributor to uncertainty in our results because the range of turbulence-induced deposition rates reported for respirable-sized aerosols is small in comparison to differences in performance among air cleaning devices indicated by our analysis.

4. Methods: Considering the potency of mite and cockroach allergens to sensitize and exacerbate asthma symptoms [4, 5], these were surprisingly not included in the models. While, it is acknowledged that particles associated with these allergens are big and would not remain suspended in the air over long periods, activities (similar to those described for cat allergens) can re-suspend them. These are important and controversial points that are of great interest to Indoor Air scientists. Please explain these omissions.

We chose to omit mite and cockroach allergens because mite allergens are significantly greater in size than cat allergens (reportedly 10-20 microns compared to 0.5 – 10 microns) and there is no solid data to show that residential air cleaners can effectively control airborne levels. We have added language to the introduction noting that we omitted these important allergens and the reasons for doing so.

5. Methods, P10, 1st para: It is true that smaller particles can deposit into deeper recess of the lungs and thus constitute a higher risk in presenting an asthmatic outcome. However, fungal spores are not inanimate -- Fungi may produce toxic secondary metabolites, allergens, and other biologically active molecules derived from fungi can be transported by means other than intact spores (e.g., hyphael fragments, fragmented spores, and dust particles) [6]. It is also to be noted that exposures to fungi greater than 5 microns can result in asthma as reported by Reponen [7]. Discuss the limitations of the assumption of aerodynamic diameter of 2.5microns for fungal spores.

Unfortunately, we could not consider allergens on smaller particles such as hyphael fragments in our modeling because time-resolved data were not available on the concentrations of these materials in the outdoor air. We have added the following text to the methods section identifying the effect of restricting the
analysis to 2.5 microns in terms of fungal fragments and for spores larger than 2.5 microns:

Fungal allergens are borne by spores larger than 2.5 µm as well as hyphal fragments and fragmented spores smaller than 2.5 µm. Because of the absence of information on fungal fragment levels in outdoor spore data for Cincinnati and the paucity of large spore types in the data, we established 2.5 µm as a reasonable central estimate of the aerodynamic diameter for fungi in this analysis..

6. Methods: Numerous reports have documented associations with exposure to respiratory syncytial virus (RSV) with asthma [5, and references therein, 8]. Again, the article will be significantly enhanced if RSV is used instead of the common viruses presented. If data is lacking for the input parameters in the model or for some other reasons, please discuss accordingly.

We did not consider RSV or other respiratory viruses primarily because input data needed for the model such as quanta emissions were not available. We have revised the text of the methods section to note that other respiratory viruses capable of exacerbating asthma symptoms were not modeled for this reason.

7. It is unclear if CONTAM can dynamically model accurately removal processes of viral particle associated with drying [9,10] i.e. at any specific moment viral particles are entering (decreasing into) a size-range as a consequence of drying while at the same moment viral particles are leaving (falling out of) that size-range as a consequence of the same processes as well as air exchange, gravitational and surface removal. Please discuss.

Our modeling did not dynamically adjust particle sizes due to drying, as CONTAM is not capable of modifying particle sizes after emission. However, the input data used for the viral particle sizes, reported in Nicas et al 2005, were particle sizes after the particles have reached equilibrium size (i.e. post drying). As discussed by Nicas et al 2005, the evaporative process occurs very rapidly (less than 0.5 sec) and therefore we believe that the use of this particle size distribution is valid.

8. Results, p12, 2nd para: What is the magnitude of the uncertainties? For that matter, what are the errors associated with modeling the different asthma triggers?

We have made an assessment of the uncertainties of the modeling in the discussion section. Included text:

Prior performance evaluations of CONTAM demonstrate that the model provides a reasonable degree of accuracy for the types of indoor air quality simulations upon which our analyses rely. Inter-zonal airflow predictions from CONTAM simulations of a single story home were within 15% of corresponding measured values [29]. Similarly, air exchange rates for a single room building predicted with CONTAM were within 5% of measured levels [24]. In a related analysis, the correlation between predicted and observed concentrations of a conservative gas ranged from 0.95 to 0.998 during six tests within a single room test home [25]. In a tracer gas study conducted in a multi-room occupied townhouse, gas concentrations predicted by the model were within 25% of measured
concentrations [26]. Finally, measured and predicted 24-hour average concentrations of 0.3 to 5 µm particles in a single room building were within 30% of each other [24].

Particle removal efficiencies for air cleaning systems considered in this analysis were derived from empirical data obtained from test homes or test chambers [21, 22]. Removal efficiencies for the portable air cleaners were based on chamber studies of four different devices that all claimed to have HEPA filters but whose efficacy under controlled conditions was low compared to HEPA standards [21]. If we had assumed that the portable air cleaners had removal efficiencies approaching those of HEPA filters, those systems would have compared more favorably to the other devices for the rooms of the homes in which they were located. Whole house comparisons of portable and in-duct systems are unlikely to have been changed substantially if we had assumed a higher aerosol removal efficiency for the portable devices.

9. Discussions, p20, 1st para: I would exercise caution in advocating the use of ducted systems to reduce exposures in mitigating asthma symptoms. Epidemiological surveys [11, 12] showed that poorly maintained system or ducted systems are associated with higher odds/risks of health outcomes. Presumably these are due to microbiologic amplifiers within the systems [11, 13]. Please include a caveat and discuss this important point.

While several studies have demonstrated that poorly maintained HVAC systems are associated with respiratory symptoms, these studies do have limitations. For example, in the Mendell analysis of the NIOSH buildings, the authors did not link air concentrations of bacteria or fungi to respiratory symptoms or to HVAC condition. However, we do believe that it is important to properly maintain any type of HVAC system and therefore changed the language to note that the HVAC systems should be properly maintained for optimal performance.

Specific Minor Comments:

1. Methods, P 9, 2nd para: particle size of ETS…reference should be [41]. Please change.

   The reference has been corrected.

2. Methods, P 11, 2nd para: please include reference for the qPCR application.

   A reference for the qPCR methodology (Van Elden et al) was included.

3. Results, p14, 1st para: The lowest spore levels given in Tabl 4 is HE.

   The text has been corrected.


   The paragraph has been corrected.
5. References: please ensure that all references follow the requirements of EH. e.g. some journals were abbreviated other spelled out, some capitalized others were not.

All the references have been corrected.

6. Tables 1-2, 6: references should be numbered as per EH requirements instead of for e.g. Chen et al (2006). It should read Chen et al [21]

The references in the tables have been corrected.

7. Table 3: Please include a footnote for definitions of DH28 and DH72.

We have added to Table 3 a note detailing which template was the single story home and which template was the two story home

8. To be consistent with the tile and more accurate, the first rows of Tables 1, 4 and second rows of Tables 1, 3, 4, 5 and 6 should read “Ventilation/filtration” instead of “ventilation” alone.

The tables have been corrected.

Comments from reviewer Otto Hänninen

1.1 - demonstrate that the CONTAM model has been validated, give citations to peer reviewed works where this has been published, and add a paragraph in the methods to shortly describe the model evaluation results.

We have included a paragraph detailing the validation studies on CONTAM to date in the methods section. The new paragraph describes several studies, primarily conducted by NIST. One study in particular examined measured and predicted particle levels in a test home.

1.2 - the model assumptions/quantification of indoor air re-circulation and passive/active (pressure difference induced) mixing of air between the compartments is a central factor affecting the results e.g. concerning emissions in a particular room. The authors have to add a paragraph to the Methods section explaining how the model handles the mixing.

A paragraph has been added to the beginning of the methods section describing how CONTAM handles transport between zones and mixing. Similar to other IAQ models, CONTAM calculates airflows between zones based on pressure differences and then calculates pollutant concentrations based on mass balance. The model assumes that each zone is well mixed and the mixing occurs instantaneously.

Minor Essential Revisions, including Discretionary Revisions

Introduction
2.1 p 4, 1st para: figures given on asthma prevalence in the US (6.7 and 8.5%) are presented with artificial precision. Due to the difficulties in definition (e.g. temporal aspects) and diagnosis
of asthma-related symptoms, any estimates of asthma prevalence in the population have less than one significant digit precision; therefore presenting the prevalence with two is not justified.

We agree that there are difficulties in obtaining accurate asthma statistics. However, the values we cited are directly from the cited ALA publication. We changed the text to denote that these values were “reported” in the ALA literature.

2.2 p5, last para of Introduction; the last sentence is evaluating the results, ie. presenting conclusions of the study (and as such, is formulated too weak to be useful); move to the conclusions and reformulate to mediate the value of the results

We have removed the last sentence of the introduction and reformulated the last paragraph of introduction.

Methods
2.3 Validated CONTAM model. The authors refer to the CONTAM model the whole work is based on as being validated, yet the only citation given for this model is the User’s Guide, not expected to be a source of scientific validation. The User’s Guide itself cites 8 references, none of which is a scientific publication. While the model itself may be valid and validated, neither of these basic requirements for the current paper is demonstrated by explaining the type of validation, showing validation (or evaluation) results, or by citing material showing these. Addition of the needed references and short 1-paragraph summary of the conducted validation/evaluation tests of the model is crucial.

Details regarding model validation studies have been added to the methods section.

2.4 Besides the detached house templates in the additional materials, the floor area (m²) should be given in the text. As the modeling is considering detached houses only, it would be interesting to read what percentage of the US populations do live in such conditions. Moreover, it is possible, that the Hispanic population groups, suffering more from asthma symptoms may have different percentage of detached house residences than the other ethnic groups. As these details are brought up by the authors as a motivation for the work, it would be interesting to push the aspect few figures further. In the discussion section it will be interesting to consider how the modeling results would apply for non-detached housing types.

We have added the floor areas of the templates to the text. Additionally, details regarding the number of people in the US living in single-family detached homes including subgroups such as African Americans and Hispanics, have been added to the methods section to indicate the number of people living in the modeled home types.

The ventilation model.
2.5 Currently the ventilation model details are started with meteorological inputs, which at least for this reviewer would be the least interesting in understanding the model setup; ie. I would move this paragraph together with the first para on p8, where the temperature-dependent probabilistic window and door opening schedules are explained. This also brings together the 1st and 3rd para on page 6, which both concern the housing templates.

Rearranging the method section was an excellent suggestion and so as suggested we moved the description of the meteorological data down in the methods section.
2.6 Air re-circulation and mixing of air between the rooms should be explained in an additional paragraph.

As discussed above, we added a paragraph at the beginning of the methods section describing air recirculation and mixing. Additionally in the paragraph in the method section describing the ventilation systems, we note the locations of the diffusers and air returns for each template.

Cat allergen
2.7 Page 8: Fel d 1 not explained. The cat allergen emissions were described using a constant and an intermittent source; former in all rooms except bedrooms, and latter once an hour during the waking hours in the living room only. These emission characteristics are hypothetical based on expert judgment. Nevertheless, the CONTAM assumptions related to the mixing of air between rooms becomes significant and should be explained in few sentences where the model is introduced. Here it is also significant to consider the use of doors between the rooms (e.g. concerning the recommendation of not allowing cats to the bedrooms requires to keep the bedrooms closed, lowering also air mixing between the bedroom and rest of the house)

We have identified cat allergen, Fel d 1. As discussed above, we added information on how the model handles transport between rooms (i.e. zones) including simulation of airflow between rooms when the door between them is open and closed.

Fungal spores:
2.8 report the mean and range (or variability) of the spore concentrations (not given in Table 2 with the other source data; add there or in the text). Spore size up to 50 µm must be mixing spores with fungal filaments.

As suggested, the sentence describing the descriptive statistics of the fungal spore data has been moved from the results section to the methods section. We described the range of spore sizes to show the diversity. We have changed the text from 50 um to 40 um as studies have shown that Alternatia sp. can have aerodynamic diameters in this range.

Viruses
2.9 The second half of the main paragraph on page 11, starting "For the in-duct electrostatic…", referring to qPCR analysis, remains unclear. I would recommend to leave it out (or shorten substantially), and to clarify what the previous sentence, citing [22], actually means – i.e. give numeric data on the test results.

We feel that it is important to include the information on the qPCR analysis as it describes a novel method. We have revised the text in an attempt to make it more clear.

2.10 Wells-Riley equation needs a reference [58]. The breathing rate of 0.48 m3/h corresponds to daily average ventilation volume including sleep/resting. Higher quanta emission rates being related to wake-up hours, higher ventilation rate for the exposure might be justified. Spending time in the adjacent room again highlights the need to describe how the model is estimating the room to room air mixing.

We have added the omitted citation for the Wells-Riley equation. Higher breathing rates would result in higher infection rates, as the breathing rates in the Wells-Riley equation are only associated with the exposure to quanta, not the emissions of quanta. As
discussed above, we have included information on how the model handles mixing between rooms.

Results

2.11 Reported similarity of the results between the two housing templates guided the authors to present only the results for the newer two-storey house (DH28). This is in slight contrast with the population relevance; while people having the option to live in two storey detached house have also good resources to choose between alternative ventilation systems, it seems to this reviewer that such a setup concerns only the highest percentiles of household income, and therefore has limited significance to contribute to the alleviation of asthma symptoms as a public health problem.

We agree that this analysis leaves out individuals that live in homes that are not single family homes and it may be possible that those living in single family homes have more resources to devote to ventilation systems. Analysis of multi-dwelling buildings would be interesting to conduct as part of additional research.

While this study did not comprehensively model all types of housing stock, a large fraction of the US population live in single family homes (61% of all homes in the US) and over 55% of Hispanics and African Americans live in single family attached or detached homes (data based on Year 2000 US Census – the US Census defines attached single family homes as those with their own heating/ventilation system and therefore would be amendable to the in-duct filtration units we analyzed). These data indicates that a large fraction of the whole population and races that have been identified as having higher prevalence of asthma live in single family homes that can potentially benefit from the use of air cleanings systems with high whole house CADR.

ETS

2.12 Page 13 Comparing the HE and CP2 systems using the median seems a bit exaggerating. The hourly median of course concerns hours when smoking is not taking place (smoking in the living room modeled for the morning and evening hours only), and therefore affected strongly by the overall ventilation rate as well as the filtration of the air. Using a linear dose-response model, the mean concentration (for the time of occupancy (different time-activities for e.g. a working adult/school child/pre-school child/house wife) would be most relevant parameter for the comparison.

We understand this comment to mean that the reviewer believes that average concentrations weighted by the amount of time a hypothetical person is inside the home would be a more meaningful measure of air cleaner performance than the simple time-weighted average concentrations presented in the manuscript. We agree in principle that exposure concentrations are more meaningful for health than simply indoor air concentrations. Nevertheless, the number of additional assumptions about stereotypical time-location patterns for people that would required to estimate exposure-weighted concentrations does not seem warranted at this time. In addition, the heterogeneity in lifestyles and patterns of time use in the U.S. and other nations limits the utility of that type of analysis. Finally, the raw results of our analysis reflect 1-hour average concentrations estimated for an entire year and are available upon request to anyone who would like to perform additional analyses including the type suggested in this comment.
2.13 The text citing Figure 3A,B states that Feb 1 is representative day; would it be more precise to state it is typical day?

We agree that a more precise definition is a “typical” day and therefore have changed the text as suggested.

2.14 Smoking event takes approximately 6.5 minutes; during this time the air exchange in all windows-closed scenarios should have a limited effect on the peak concentration. Is it correct that the difference between HE and C1 is 2-fold (40 vs. 80 µg m-3)? This sounds un plausible for the living room; I would expect similar magnitude for the peaks with lower spread to the other rooms of course in the case of HE, as well faster decline. Is it possible that e.g. the C1 smoking event may take place during the non-operating phase of the AHU? (but still this would not explain 2-fold difference!)

The reviewer suggests that the difference between peak ETS values are approximately 80 and 40 µg/m3 for conventional and HE filtration, respectively. The figure may have been misread because as shown in Figure 3, the two peaks are approximately 120 and 140 µg/m3. This difference in peaks is as the reviewer expects of a similar magnitude. Operating times for the AHU were the same for the HE and C1 case and therefore could not impact the differences seen between the two filtration types.

Outdoor Fungi
2.15 Page 14 – the first sentence gives the spore ranges that belong (and were requested in my previous remark) to be presented in the methods. These are inputs to the current work, not a result.

As noted in comment 2.8, the spore range information has been moved to the methods section as suggested.

2.16 The last sentence states that the lowest levels in "the bedroom", while in Table 4 the lowest figures in "Bedroom 2" are reported for HE (41 against 52-54).

The reviewer has identified an error in the text concerning fungal levels in the bedroom. We have corrected the text to indicate that the high efficiency system yields the lowest bedroom concentration.

Viruses
2.17 The text presents three time-activity scenarios (very good). Numerical results are split in Tables 5 & 6, with results for the second scenario missing. I would suggest to combine all results in the same table, adding the missing scenario.

As suggested by the reviewer, Tables 5 and 6 have been combined and information for the second infection scenario has been included in the new table.

Discussion
2.18 Please consider in the discussion

a- indoor sources of fungal spores; to what extent the results are the applicable?
Generally speaking, we feel our results are applicable to fungal spores from indoor sources in that the use of a high-efficiency system with a high CADR is likely to yield the lowest overall indoor concentrations. However, the location of the indoor source would play a role and therefore a portable unit may yield the lowest concentrations in an individual room, similar to the infection scenarios. We have included text on this point in the discussion section.

b- non-detached house types; IAQ problems in detached houses; health problems of populations living in detached houses; applicability of the results to other types of buildings?

We have added a sentence to the discussion noting that we would expect systems with high CADR to impact attached homes in a similar way to detached homes. The extent to which high CADR whole house and other air cleaning systems influence indoor environmental quality in practice remains to be determined. The potential benefits indicated by the modeling suggest that carefully designed and executed panel or cohort studies that include high CADR air cleaning systems as a main effect warrant consideration for future research.

c- non-inhalation based spread of contagious units; this may have serious practical implications for the interpretation of the presented inhalation spread results

The reviewer notes that the airborne route of exposure is not the only transmission route for respiratory viruses such as rhinovirus and influenza virus. We had added a several sentences to the discussion noting this issue and our thoughts on the implications of the results.

References
2.19 References 1, 2, 21, 23, 24, 25, 27, 30, (43), 54, 66 have to provide url-links.

All references have been updated.

Table 1
2.20 CP1, CP2 -> C+1P, C+2P (Conventional forced ventilation with 1 inch filter operated together with 1 or 2 portable HEPA filter devices (details in parentheses) HE: Forced ventilation with high efficiency filter (details in parentheses)

As suggested by the reviewer, we have changed the abbreviations to those suggested by the reviewer. The new abbreviations are more comprehensible.

Table 2
2.21 The emission rates are presented with ridiculous 0.1 ng/h precision (the authors are asked to consider also the relevant precision for the other variables, e.g. particle size and filtration efficiency with 3-digit precision?).

We believe that the emission rates used in the model are on an hourly basis consistent with the temporal resolution of the analysis. The rates used in the model are scaled from empirical studies that provide information over longer averaging times. The apparent precision is therefore correct to the extent that the processes being modeled are continuous.
2.22 It is unclear if the particle sizes, deposition rates, and removal efficiencies are used as point values or as a probability distributions (in which case the parameters describing the spread are missing).

The values such as particle sizes, deposition rates and removal efficiencies are point values. The model does not allow for the use of probability distributions.

2.23 Unit of measure for the particle sizes and efficiency rates missing (µm, %?)

We have added the missing units of measure

2.24 Replace "Mold" with "Outdoor fungal spores" to avoid confusion with indoor mold

We have changed the language in the table to “outdoor fungal spores"

Table 3
2.25 Column titles incomplete (e.g. "Template" is not readily comprehensible – add "House"; add column title for air exchange rate (the precision of 3 digits is exaggerated) Are the percentiles for the time during the annual simulation? What explains the large variation of the forced ventilation rates? Times windows are kept open?

We have changed the column title and the precision of the ACH. The percentiles are for the time during the annual simulation and therefore reflects periods in which the windows were open and closed. As suspected by the reviewer, the variation is due to the changes in ACH due to windows opening and closing.

Table 4
2.26 Indicate units in the caption or header row, not in footnote (GM, GSD) Ventilation codes cryptic – spell out sp/m3 => 1/m3 or spores/m3. Clarify "Bedroom 2" (clear in the housing template, but is this the bedroom with the portable cleaner or not?)

All suggested changes to Table 4 have been made.

Table 5
2.27 Three digit precision for infection risks is meaningless

The precision of the infection risks have been reduced as suggested.

Figure 3A,B
2.28 In the text expression "Living room" was used. The figures use "Family room"; may confuse some readers. The substantial difference between these two settings suggests to me that the model is assuming that all mixing of air between the rooms is assumed to take place via the air re-circulation. If this is the case, passive mixing may be underestimated, producing unrealistically good results for all scenarios with indoor sources in a specific room.

Template 28 has both a living room and family room. Template 72 has only a living room. We have noted that releases of ETS and cat allergen occurred in the main living space (i.e. the living room in template 72 and the family room in template 28).
As discussed above, mixing of air between room takes place via air-recirculation and through the movement of air between rooms based on pressure differences.

Review by Jonathan A. Bernstein

I am also concerned that the study was funded by TRANE and the conclusions just happen to indicate the central HVAC system functions superiorly compared to stand alone units.

The empirical data on removal efficiency and rates used in our modeling paper were based on our prior measurements of an in-duct air cleaner manufactured by Trane Residential Systems. However, any in-duct system with the same particle-size specific removal efficiency or any portable system with an equivalent clean air delivery rate would have approximately the same effectiveness as the Trane system that we modeled. In the conclusions we note that our results suggest that any system high efficiency in-duct system will yield the best control of asthma triggers.