UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards (OAQPS)
Research Triangle Park, North Carolina 27711

MEMORANDUM

To: O_3 NAAQS Review Docket (EPA–HQ–OAR–2008–0699)

From: Stephen Graham – Physical Scientist, Risk and Benefits Group OAQPS

Date: September 24, 2015

Subject: Further Evaluation of Ozone Exposure Model Input Data in Response to Comments

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Overview

The EPA received a number of comments expressing divergent views on the estimation of O_3 exposures in the Ozone Health Risk and Exposure Assessment (HREA; U.S. EPA, 2014) using the Air Pollution Exposure model (APEX) model, its associated model input data sets, and algorithms. This memorandum presents further technical details in responding to a few comments made regarding input data used in the human exposure modeling performed for the HREA. Three sections follow, addressing particular comments made on the human activity pattern data used, an evaluation of ventilations rates estimated by APEX, and a commenter's concern regarding ozone ambient monitoring probe heights and estimated exposures.

1. Activity Pattern Data Used by APEX

Comment:[1] A few commenters suggested that the time spent outdoors modeled by APEX was greater than that expected. Specifically, "*In the ozone ISA (Table 4-4), EPA noted that the National Human Activity Pattern survey data (NHAPS) show that the average time a 5- to 17-year-old spends outdoors is 7.88% of the day, or 1.9 hours. We would expect that many of the APEX-simulated children experiencing FEV1 decrements > 10% would spend more than the average amount of outdoors, since there is a greater probability of high ozone exposures outdoors than indoors. However, API Figure II.1 demonstrates that a number of the modeled children spent an unrealistically high amount of time outdoors (e.g., up to 24*

[1] This comment/response appears in the Response to Comments document in section II.A.1.c.i under the subheading "Comments on Activity Pattern Data Used by APEX."

hours), which suggests that the model does not always accurately simulate the daily activity patterns of children and the exposures that result from these activities" (e.g., American Petroleum Institute (API)) [2].

"[S]ome of the children with FEV1 decrements greater than 10% were simulated by APEX to spend a large percent of the day outdoors (e.g., up to 24 hours per day on the days when they experienced the lung function decrements). This can be contrasted with the National Human Activity Pattern survey data that show that 5- to 17-year-olds, on average, spend 7.88%, or 1.9 hours, of their day outside. These data demonstrate that not all of the children in the APEX model are realistically simulated, and that the number of simulated children with FEV1 decrements greater than 10% is likely overestimated" (e.g., Gradient).

Response: We disagree with the commenter's interpretation of activity pattern data and their conclusions drawn regarding what is an "unrealistic" amount of time spent outdoors for children or any study group modeled by APEX. The Consolidated Human Activity Database (CHAD) is the most comprehensive collection of activity pattern data available for appropriately modeling short-term human exposures. The CHAD data are an accurate record of the locations where actual surveyed individuals visited (e.g., outdoors at school) and their activities performed (e.g., play sports). The CHAD data are used in APEX "as is" or unadjusted from when the activity pattern information was originally collected from the surveyed individuals. There are many diary days in CHAD where study participants had absolutely no time spent outdoors (i.e., 0 minutes) and an extremely limited number of diary days where survey participants spent the entire day (i.e., 24 hours) outdoors, while other diary days fall somewhere in between. This is the nature of human activity patterns and the data recorded to represent them.

Comparing time budgets of select individual diary days used by APEX for when children experienced lung function decrements (Figure 1, top panel)[3] to aggregated, time-averaged diary data (i.e., all of NHAPS data) as was done by the commenters is inappropriate. A more appropriate comparison of time expenditure using the commenter reported NHAPS time-averaged results is first illustrated in Figure 1 (bottom panel), showing the complete distribution of time spent outdoors for children ages 5-17, using all of the CHAD diaries used by APEX for this study group (n=15,832 diary days). As shown, the distribution indicates that less time is spent outdoors on average using the full set of diaries in CHAD (i.e., mean = 1.4 hours, standard deviation = 2.1 hours, Table 1), than when compared with that

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[2] The commenter performed APEX simulations to generate Figure II.1 and II.2, duplicated in this memorandum in Figures 1 (top panel) and Figure 3 (top panel) from that commenter's document. The commenter "reproduced EPA's APEX model simulation for the base air quality in Los Angeles in 2006, and further analyzed the profiles of the simulated individuals who experienced FEV1 decrements > 10% and > 15%. This simulation was based on the same input files and parameters as the simulation reported in the HREA. The only difference is that, instead of modeling 200,000 individuals aged 5-95, we modeled 200,000 individuals aged 5-18 because of the focus in the PR on children in this age range (HREA)." (API).

[3] Obtained from API.

generated using the commenters' mentioned statistics regarding the NHAPS data alone (i.e., a mean of 1.9 hours of outdoor time). Note also that the NHAPS activity pattern survey data contribute to a large portion of the diary data included in CHAD and used by APEX in estimating exposures (~20% of all CHAD diaries, see Table 5-3, HREA). Given these general statistics for time spent outdoors, it suggests that if the NHAPS data alone were used in estimating exposures by APEX rather than all of CHAD, it is possible that the number and percent of persons at or above benchmark levels would be greater than that reported in the main body HREA results that used the entire CHAD database to simulate individuals and estimate exposures.

Further, often overlooked in when performing time-averaged comparisons or when focusing only on maximum values is whether the individual activity survey participants spent any or little time outdoors and what proportion of the population these people comprise (i.e., considering the full distribution of time expended for the population). The results of such an analysis are reported below using all of the CHAD diaries for children ages 5-17 in Table 1. Approximately 45% of CHAD diary days for children ages 5-17 have absolutely no time spent outdoors (0 minutes). Just over half did not spend greater than 30 minutes outdoors, with nearly 60 percent having less than a single hour of time spent outdoors. Regarding time spent outdoors for an entire 24 hour period, a concern expressed by the commenters, there were only four diary days that were used by APEX having that amount of time spent outdoors, comprising 0.025% of the total number of available diaries (15,832) for children ages 5-17. Inspection of the location information recorded on these four diary days indicated that most of these surveyed children spent time outdoors at a park (CHAD location codes 35800 and 35810) or by a pool/river/lake (CHAD location code 35900). It is certainly reasonable and entirely not "unrealistic" that when these diary days were initially recorded by the study participants, the children surveyed were participating in an outdoor camping event, as some of the recorded activities include hiking/fishing or other recreational sports. Further, given that these are recorded events from actual children, it is certainly not at all "unrealistic" to also include these diaries having time spent outdoors as long as 24 hours in the APEX exposure simulations.

Thus, not only are the CHAD diary data accurate representations of what actual people do, indicate where they visit and the time associated with each of these events, the meant time spent outdoors for CHAD survey participants is consistent with the NHAPS data statistics cited by the commenter. Moreover, the commenter's approach of highlighting group means alone masks the importance of considering observed interindividual variability in daily time expenditure and associated pollutant exposures – in this case, disregarding children spending longer amounts of time outdoors than the average and that are likely to experience the highest O_3 exposures.

2. Ventilation Rates Estimated by APEX

Two comments were made regarding ventilation rates that required detailed analysis and discussion.

2.1 Appropriate evaluation of mean ventilation rates and associated variability

Comment:[4] A few commenters suggested that APEX overestimated ventilation rates. Specifically, one commenter suggested "*the APEX model predicts more elevated ventilation rate occurrences than observed in real world data. In the previous review, Langstaff acknowledged that the 'values produced by the ventilation rate algorithm may exhibit an excessive degree of variability' [(Langstaff, 2007)]. An excessive degree of variability will produce an excessive number of extreme values of ventilation rate. The 1997 EPA analysis had also over-estimated the number of high ventilation rates in the population by using an algorithm to assign ventilation rates based on individuals who exercised regularly and were motivated to reach a high ventilation rate. As a result, the 1996 Staff Paper acknowledged that the analysis allowed more high ventilation rates (hence greater risk) than would actually occur in the populations of interest - outdoor workers, outdoor children, etc. The final HREA includes a comparison of predicted ventilation rates with mean values in the literature, but the upper tails of the distribution which impact the risk estimates were not compared. This was an important oversight because the upper percentiles of ventilation rate are responsible for the exposures that cause the perceived risk.*" (e.g., AAM; U.S. Chamber of Commerce).

"*EPA acknowledges that the ventilation rates used in the APEX model can be greater than published measurements by 2-3 m^3/day (HREA), but does not acknowledge that this contributes to overestimated exposures and lung function decrement risks*" (e.g., API).

"*In addition, according to the HREA (p. 5-64), APEX ventilation rates can be overstated by 2-3 m^3/day, which is a significant overestimation in comparison to typically assumed daily inhalation rates of 20 m^3/day (i.e. 10-15%)*" (e.g., TPA).

Response: EPA disagrees with the commenters' use of information provided in former and recent O_3 NAAQS-related exposure assessments and the conclusions drawn by the commenters regarding the current APEX modeling approach used to estimate ventilation rates. A few corrections to the commenter's statements are first needed here. Regarding the reference to an assessment performed for the 2007 O_3 NAAQS review, EPA specifically notes here that the statement regarding 'excessive variability' was not directly made by Langstaff (2007) but actually refers to a statement made by Johnson (2002, 2003) pertaining to estimating metabolic equivalents of work (METs) that would lead to "VO_2 [oxygen consumption] values which exceed limits based on activity duration and the physiological characteristics of the cohort" (Johnson, 2002). A commenter's mention that "the 1997 EPA analysis had also over-estimated the number of high ventilation rates in the population" actually refers to a statement made in the 1996 O_3 exposure assessment (Johnson et al., 1996) regarding the approach used at that time by the probabilistic NAAQS exposure model (pNEM) to estimate ventilation rates, where

[4] This comment/response appears in the Response to Comments document in section II.A.1.c.i under the subheading "Comments on APEX Estimated Ventilation Rates."

eight lognormal distributions[5] of equivalent ventilation rate (EVR) were randomly sampled to estimate breathing in simulated exposure cohorts (not for simulated individuals as is done currently by APEX). Johnson et al. (1996) states, "[c]onsequently, the EVR limiting algorithm may permit more high EVR values to occur in the pNEM/O_3 simulation than would occur in the actual population. This potential bias may be corrected in future versions of pNEM/O_3 by distinguishing cohorts by gender, age, and physical conditioning" (see Johnson et al., 1996).

Assessments of older approaches (some nearly 20 years old) used to estimate ventilation in earlier NAAQS reviews are not relevant to evaluating the ventilation approach used in the current APEX model. EPA has since specifically addressed the above identified issue of controlling for physiologically unusual VO_2 by appropriately modeling fatigue in APEX simulated individuals that could occur with sequentially-repeated high-exertion activities, while also accounting for increased ventilation that is expected to occur following completion of high-exertion activities (i.e., excess post exercise oxygen consumption, EPOC) (Isaacs et al., 2008; U.S. EPA, 2012a; U.S. EPA, 2012b). Furthermore, both the 1996 EPA exposure assessment (Johnson et al., 1996) and Johnson (2002, 2003) used/assessed a different algorithm used by APEX to estimate ventilation rates that has since been updated and currently accounts for important influential variables such as age, gender, and body mass (Graham and McCurdy, 2005). While the Johnson (2002, 2003) algorithm used an individual-based activity-specific ventilation approach much like the approach used for the HREA, Graham and McCurdy (2005) expanded the clinical data set originally used in Johnson (2002, 2003) by approximately 600 measurement data points (now comprising 6,284 observations) and extended the algorithm to improve the estimation of ventilation rates in children less than 18 years old. Therefore, any comments made that are supported by an assessment of obsolete modeling approaches, and which pertain to older, more limited data sets, are not relevant to the current ventilation algorithm used by APEX.

EPA also disagrees with the commenters' interpretation of available literature-reported ventilation rates including how they compare to APEX estimated ventilation rates. In their evaluation, the commenter emphasizes data reported in Table 25 of Langstaff (2007) that compares mean (± sd) daily ventilation rates estimated by APEX with ventilation rates estimated by Brochu et al. (2006). The commenter concluded that, based on the results presented in these two selected sources of information and because APEX simulated daily mean (and standard deviation) ventilation rates were higher than Brochu et al. (2006), the APEX results are over-estimated. Interestingly, in their comment, the commenter references the first part of a statement provided in Table 5-10 of the HREA that begins with "the APEX estimated daily ventilation rates can be greater (2-3 m^3/day) than literature reported measurement values (Table 25 of Langstaff, 2007)," but then fails to acknowledge the latter and more important portion of the sentence "though if accounting for measurement bias this minimizes the discrepancy (Graham and McCurdy, 2005; see Figure 5-23 and Figure 5-24)" (see HREA). Additional clarity is

[5] Each distribution used in this older approach to estimating ventilation rate is specific to a broad study/age group (children or adults) and breathing rate category (i.e., sleeping, slow, medium, or fast) and were derived from a limited study that used 36 participants aged 10 to 50 years old (Johnson et al., 1996).

provided below regarding the Brochu et al. (2006) ventilation data set and the Langstaff (2007) reported results for APEX ventilation rates, then followed with additional analysis to respond to the above comments.

The Brochu et al. (2006) data were based on doubly-labeled water (DLW) consumption/elimination to estimate energy expenditure in healthy normal-weight males and females over a 7-day to 21-day period (Brochu et al., 2006). This extended period used to estimate energy expenditure is standard with this approach, resulting from the several hours it takes for the administered ^{18}O and ^{2}H isotopes to distribute throughout the bodies of study subjects and the daily measurements needed to evaluate the progressive decrease in isotope concentrations over time (McArdle et al., 2001). Thus, within person day-to-day variability in ventilation rates that is expected to occur is not accounted for by this method, immediately unrealistically constraining variability in their reported results, even when considering these daily mean values reported by Brochu et al. (2006).

More so however, the principal issue commonly ignored when evaluating the Brochu et al. (2006) data, but stressed in the HREA (section 5.4.4.2) and the Graham (2009) evaluation of the Brochu et al. (2006) reported data, is that the Brochu et al. (2006) study did not directly measure ventilation rates. Ventilation rates in the Brochu et al. (2006) study is a calculated value, an approximation constrained by its own set of assumptions (and differing from the assumptions used to simulate ventilation rates in APEX). The most important assumption made by Brochu et al. (2006) and discussed in the HREA is their assuming a single ventilatory equivalent ratio for oxygen (VQ) equal to 27, a factor used to calculate ventilation rate for all persons, both sexes, and all ages without consideration of exertion level. A VQ point estimate of 27 could be a generally reasonable approximation for estimating a mean ventilation rate in adults while performing low exertion activities (e.g., LeMura and Von Duvillard, 2004), however it is less appropriate for use in estimating ventilation rates associated with moderate or greater exertion activities (e.g., LeMura and Von Duvillard, 2004), is less than values more commonly used in estimating ventilation in children (e.g., Arcus Arth and Blaisdell, 2007) and entirely unable to realistically capture short-term intra- and inter-personal variability in ventilation rates.

With this in mind, the distribution of Brochu et al. (2006) ventilation estimates used by the commenter (Figure 2, top panel)[6] were corrected here (and as was done for a similar evaluation in the HREA) using an independent, more appropriate VQ estimate of 30.6 offered by Arcus-Arth and Blaisdell (2007) and used to re-calculate ventilation rates for children ages 7-10. When the Brochu et al. (2006) distribution of daily ventilation rates are corrected, it is nearly identical to that estimated by APEX, both regarding the mean and the standard deviation (Figure 2, bottom panel). Further, a simulation was performed using the corrected Brochu et al. (2006) parameters that would more appropriately describe the distribution of daily ventilation rates, and even the maximum estimated daily ventilation rate closely matched that generated using APEX (20.5 m^3/day versus 20.8 m^3/day, respectively). Based on this analysis it is likely that the choice of incorrectly limiting VQ to a single value of 27 in the Brochu et al.

[6] Obtained from Alliance of Automobile Manufacturers (AAM)

(2006) study led to an underestimation of daily ventilation rates at all percentiles of the distribution, particularly for children.

The above discussion and results presented here and those included in the HREA indicate that APEX does not predict more elevated ventilation occurrences than observed in 'real world' data as implied by the commenters. The results presented here indicate that the Brochu et al. (2006) calculated daily ventilation rates are likely systematically underestimated. Further, the Brochu et al. (2006) data, even when corrected using a more appropriate VQ, could not be used to appropriately evaluate variability in ventilation rates having durations of less than 24-hours. In addition, when considering that the energy expenditure measurements used to approximate ventilation were collected over 7-14 days, an approach that compresses day-to-day variability, the Brochu et al. (2006) study likely underestimates the actual variance associated with their reported daily ventilation rates.

2.2 Appropriate evaluation of upper percentile ventilation rates

Comment:[7] A few commenters suggested that APEX estimates of moderate and greater exertion ventilation rates are above those reported in literature sources. Specifically, "*The U.S. EPA Exposure Factors Handbook (U.S. EPA, 2011, Table 6-27) presents literature values for inhalation rates at different activity levels. For children aged 3-16, the Handbook lists the following mean ventilation rates: 21-25 L/min for moderate intensity activities and 37-49 L/min for high intensity activities. Figure II.2 demonstrates that a number of the modeled children have ventilation rates that are well above those rates for high intensity activities, and in addition, it is not realistic to assume that a large number of the simulated children would approach these high ventilation rates while engaging in typical outdoor play and sports*" (e.g., API).

"[*M*]*any of the simulated children had ventilation rates above 21-25 L/min, and some had rates above 37-49 L/min, which are the ranges of ventilation rates given by the U.S. EPA Exposure Factors Handbook (U.S. EPA, 2011, Table 6-27) for children engaging in medium- and high-intensity activities, respectively. It is not realistic to assume that such a large number of children would approach or exceed these high ventilation rates while engaging in typical outdoor play and sports*" (e.g., Gradient).

Response: We disagree with the commenters' characterization of APEX estimated ventilation rates and the comparisons the commenters made with literature provided values. A correction and clarification are needed prior to providing additional response to the comment.

First, a correction to the comment is needed regarding the source of information used when comparing APEX estimated ventilation rates with that reported in the Exposure Factors Handbook (U.S. EPA, 2011). The commenters appear to have used data from Table 6-2 of U.S. EPA (2011) rather than Table 6-27 as they stated. Table 6-2 of U.S. EPA (2011) contains "Recommended Short-Term Exposure Values for

[7] This comment/response appears in the Response to Comments document in section II.A.1.c.i under the subheading "Comments on APEX Estimated Ventilation Rates."

Inhalation (males and females combined)" and includes the range of mean ventilation rates cited by the commenter for moderate exertion (21-25 L/min) and high exertion (37-49 L/min) activities for children aged 3 to <16. EPA contends these reported data from Table 6-2 of U.S. EPA (2011) are what was used by the commenters to compare with the ventilation rates output from an APEX model simulation performed by the commenters (Figure 3, top panel). Based on that comparison, the commenters suggested the APEX-estimated ventilation rates were "not realistic" because the distribution of values estimated by APEX extends beyond the range of values provided by U.S. EPA (2011).

Second, the ventilation rates reported by the commenters (Figure 3, top panel)[8] are characterized by the commenter as "Median Ventilation Rates", though information is not provided regarding how these ventilation rates were derived nor is it clear what averaging time the commenter used for the ventilation rates (e.g., hourly, event-level). Based on the counts reported in their comments (4,546) and visually approximating the counts provided in Figure 3 (top panel), EPA assumes here that the commenter has used the number of children as a point of reference in calculating their distribution of ventilation rates. A new APEX simulation was performed here to reproduce a similar distribution ventilation rates reported by the commenter using their APEX simulation.[9] Using output data from our APEX simulation, we calculated the median ventilation rate (L/min) occurring at the exact time of day when the maximum lung function decrement > 10% occurred (and included only only those children having at least two decrements). For example, if an individual had three maximum lung function decrements > 10% occurring on three separate days, the median for this child was identified in our analysis as the middle ventilation rate of the three (and potentially having an averaging time as small as 1-minute upwards to 1-hour, that is, the range of time associated with any event level ventilation rate). Figure 3 (bottom panel) presents the median ventilation rate from our new, similar simulation of exposures to children ages 5-18 in Los Angeles, yielding a generally similar distribution to that provided by the commenter (Figure 3, top panel).

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[8] Obtained from API.

[9] The commenter states "EPA reported that in the base air quality simulation, 28.03% of children aged 5-18 in Los Angeles in 2006 experienced an FEV1 decrement > 10% at least one time during the year (HREA, Appendix 6, Table 6B-10). The results of our simulation showed that 28.32% of the simulated children experienced FEV1 decrements > 10%, demonstrating that our simulation reproduced EPA's reported results". Later the commenter states "We found that 4,546 of these 25,000 simulated children (18%) experienced an FEV1 decrement > 10% on 2 or more days during the simulation period (January 1-December 31, 2006)". For this memorandum, we performed a simulation of 25,000 children 5-18 to generate a similar and comparable study group, rather than performing a simulation of 200,000 and randomly sampling for 25,000 children from this total as did the commenter. Of these 25,000 children EPA simulated, 7,113 (28.45%) had at least one FEV1 decrement >10%, while 4,553 (18.21%) had at least two FEV1 decrement >10%, indicating that we also effectively reproduced the risk results reported in the HREA and those simulated and reported by the commenter above for their APEX simulations of persons having at least 2 or more FEV1 decrements > 10%.

First, the commenters do not provide any published (or other) evidence to support their statement that "it is not realistic to assume that such a large number of children would approach or exceed these high ventilation rates while engaging in typical outdoor play and sports", rendering this statement merely an opinion. To the best of our knowledge, there is no population-based database available that accurately represents the distribution of ventilation rates that exists for all people residing across an entire urban study area(s) and over an entire year, a database that, if available, could provide insight into how many and how often children might engage in moderate or high exertion activities. The U.S. EPA (2011) data tables are not designed to address this issue. In the absence of having a population-based database of ventilation rates, EPA uses the CHAD data (i.e., activity pattern survey data based on real people that accounts for influential variables such as age, sex, day-of-week, temperature) and associated energy expenditure estimated by APEX to inform this proportion.

Second, understanding and distinguishing mean and upper percentile estimates for ventilation rates is an important consideration here, particularly considering the size of the study groups considered in the HREA. The commenter's focus on highest ventilation events addresses less than 1 per cent of the data simulated by APEX for each simulated individual. This leads to a significant low bias in all of the commenter's analyses and comparisons when using a time-averaged data to evaluate upper percentiles of a distribution. Further, the commenter did not fully consider the impact influential variables (i.e., sex, age, means vs upper percentile values, event duration) have on ventilation rates when comparing APEX estimates and the EPA (2011) recommended values. This includes the following:

1. The commenter ventilation rate comparison is biased by their using U.S. EPA (2011) reported data for children of both sexes, while the APEX distribution of ventilation rates is based on data from individuals, i.e., the distribution of ventilation rates are from simulated females and males separately. Ventilation rates for males are higher than for females, such that averaging the two will inappropriately constrict variability observed for an actual population. As a result, the commenter's comparison will make the APEX results appear to be too high when in fact, it is the commenter's comparative data which are biased low due to the combining of the ventilation rates for the two sexes. This low bias is quantifiable. U.S. EPA (2011) Table 2 does not have recommended values separated by males and females; however, there are other tables in that document that can inform how ignoring sex reduces variability in ventilation rates when they are combined (and also serve to inform the data in Table 2 of U.S. EPA, 2011). Tables 6-17 and 6-19 of U.S. EPA (2011) provide short-term ventilation rates for several age groups of males and females, respectively. Considering the age range supplied by the commenter in their evaluation, mean ventilation rates for males ages 3 to <16 at moderate exertion range from 21-26 L/min, while ventilation rates for females ages 3 to <16 at moderate exertion range from 20-24 L/min. When assessed as a group of individuals rather than as an average or composite group, the actual range of this distribution would extend from 20-26 L/min rather than the API reported range of 21-25 L/min. Using similar logic for high exertion activities, the actual range for males would be 39-51 L/min and for females the range would be 35-47 L/min, giving a mean ventilation distribution range of 35-51 L/min rather than the commenter reported range 37-49 L/min.

Overall, the comparison provided by the commenter by not considering differences in ventilation rates for males and females separately would contribute to an underestimation bias of about 4-5%.

2. The commenter biased their comparison of ventilation rates by using U.S. EPA (2011) reported data for children ages 3 to <16 to compare with the APEX estimated ventilation rates of children ages 5 to 18. 5-year old children have higher ventilation rates than 3-year old children (considering both the average and upper percentiles), as do 18 year old children compared to 15 year old children. As a result, the commenter's comparison will improperly make the APEX estimated ventilation rates appear to be too high when in fact it is the comparative data which (as above) are biased low. Again, we can use the data provided in Tables 6-17 and 6-19 of U.S. EPA (2011) to generate a reasonable estimate of that low bias here. Because the U.S. EPA (2011) data are presented for age groups rather than for individual years, a simple linear interpolation of the age group data was performed by EPA to approximate the mean ventilation rate for each of the individual age year (ages 3 to 5, ages 15 to 18) and compared. Using this approach, the comparison provided by the commenter by not considering differences in mean ventilation rates for the appropriate age groupings would contribute to an underestimation bias of about 2-6%.

3. Perhaps most importantly, the commenters biased their evaluation by comparing mean values meant to describe ventilation rates for an average individual in a population to a distribution of values representing a population of individuals. The portion of the U.S. EPA (2011) table 6-2 cited by the commenter contains recommended mean values and are not meant to be applicable to an entire population, particularly the suggestion that the mean values are appropriate to use for all individuals comprising the population. The commenter neglected to include the additional information provided in Table 6-2 U.S. EPA (2011), which also recommends 95th percentile ventilation rates for each of the selected age groups. For activities involving moderate and high exertion, U.S. EPA (2011) recommends using 27-35 L/min and 48-70 L/min, respectively, as upper bound (95th percentile) ventilation rates for children ages 3 to <16 years old. The majority of APEX ventilation rates estimated are within these 95th percentile values (see Figure 3, either panel).

And finally, in their comparison the commenter selected for individuals not considered as typical or representative of an average population by reducing the total population of simulated individuals to only the few that had two or more lung function decrements. The activity pattern events used, the ventilation rates estimated, evaluated and then contended by the commenter as "not realistic" are those that have been simulated with extremely limited frequency (i.e., two or more activity events in an entire O_3 season), particularly when considering Los Angeles' O_3 season is 365 days and the simulated individuals (children ages 5-18) could have anywhere between 24 and 171 number of activity events per day (on average, about 38 events per day). Given that on average, more than 10,000 exposure events are simulated by APEX for each individual over the O_3 season, these particular highest ventilation events isolated and emphasized by the commenter comprise only a tiny fraction of all ventilation rates (e.g., 0.02%) estimated by APEX for each simulated individual.

Thus, the data presented by the commenter are atypical of the simulated population in the study area as a whole, and are not comparable with the mean values reported in U.S. EPA (2011). When considering an upper range value for ventilation rate of 70 L/min (i.e., the 95th percentile) reported by U.S. EPA (2011), as expected there are only few individuals simulated by APEX that are above this level (e.g., using Figure 3 top panel, approximately 250 of all 4,546 children, or 5.5%, that had at least two lung function decrements). Even if the commenters ventilation rate comparison were completely appropriate (which it is not due to the age and sex biases discussed above), the overall difference in U.S. EPA (2011) reported and APEX modeled ventilation rates, considering upper percentile values is minimal.

3. Ambient monitor probe heights

Comment:[10] One commenter contends *"[t]he third way the counts of benchmark exposures are biased high relates to the fact that ozone exposure is lower at "breathing" height compared to "measurement" height (3-15 meters) as acknowledged in the 2006 Ozone Criteria Document*" (e.g., AAM).

Response: EPA disagrees with this comment regarding the potential impact of monitor probe heights relative to counts of benchmark exposures in the HREA study areas. First, there is limited information available to quantitatively inform the variation in ozone concentrations with vertical height in urban areas. Most of the discussion in the 2006 AQCD[11] that indicated the presence of a vertical gradient, also indicated it was largely attenuated by unstable atmospheric conditions, conditions likely present during daytime hours in urban areas (2006 O_3 AQCD). In addition, nearly 70% of the inlet heights for the monitors used in the HREA study areas are typically situated at a height of 3 to 5 meters (Figure 4). Taken together, while there is some information indicating decreasing O_3 concentration with decreasing monitor probe height, there are too few studies available with having appropriate data to develop a

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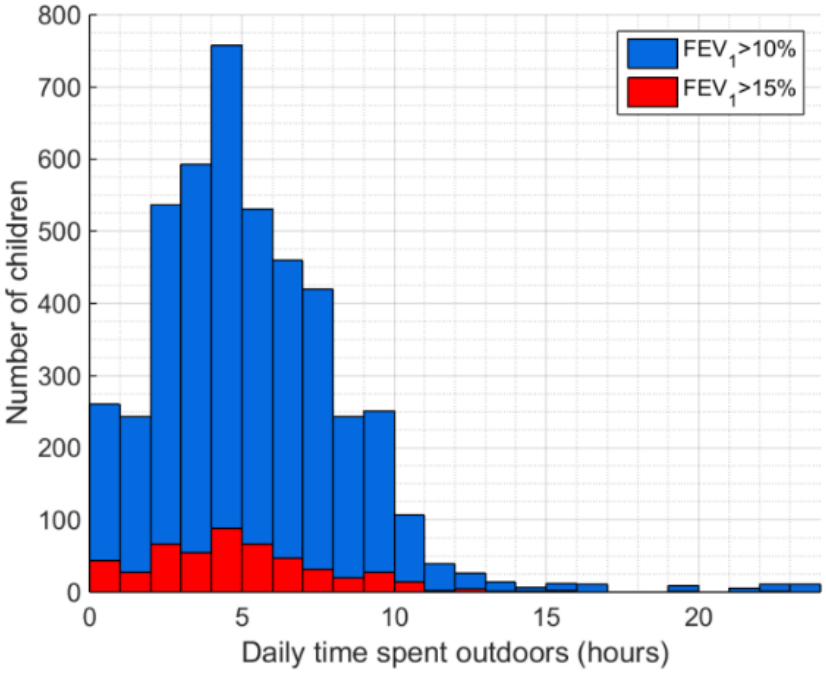
[10] This comment/response appears in the Response to Comments document in section II.A.1.c.i under the subheading "Other Exposure-Related Influential Factors."

[11] The 2006 Ozone Criteria Document (O_3 AQCD, U.S. EPA, 2006) states in a section titled "Vertical Variations in Ozone Concentrations" (pages 3-15 to 3-17) that "[m]ost work characterizing the vertical profile of O_3 near the surface has been performed in nonurban areas with the aim of calculating fluxes of O_3 and other pollutants through forest canopies and to crops and short vegetation, etc. Corresponding data are sparse for urban areas." The section in the 2006 O_3 AQCD discusses the variability in concentration with respect to vertical height at some length including influence by vegetation present and atmospheric stability and concludes, based on the information derived from non-urban studies, that the degree of atmospheric stability is important as "there was a decrease of about 20% in going from a height of 4 m down to 0.5 m above the surface during stable conditions, but O_3 decreased by only about 7% during unstable conditions" and that "the stability regime during the day in urban areas tends more toward instability because of the urban heat island effect." Later the 2006 O_3 AQCD very briefly mentions in a section titled, "Factors Affecting the Relationship between Ambient Concentrations and Personal Exposures to O3", "[s]tudies on the effect of elevation on O_3 concentrations found that concentrations increased with increasing elevation (Väkevä et al., 1999; Johnson, 1997)."

reasonable quantitative relationship in urban areas, but more importantly, the overall expected impact on the HREA estimated exposures is likely be negligible based on the probe heights of the majority of the O_3 monitors used in estimated exposures.

Table 1. Descriptive statistics for time spent outdoors using CHAD diary days for children ages 5-17.

CHAD/APEX diaries considered	diary days (n)	% of all diaries	Outdoor time (minutes)				
			mean	std	min	median	max
all children ages 5-17	15,832	100.0	82	127	0	20	1440
at least 1 minute outdoors	8,640	54.6	150	138	1	118	1440
at least 30 minutes outdoors	7,712	48.7	167	137	30	123	1440
at least 60 minutes outdoors	6,587	41.6	188	137	60	150	1440
24 hours outdoors	4	0.025	1400				



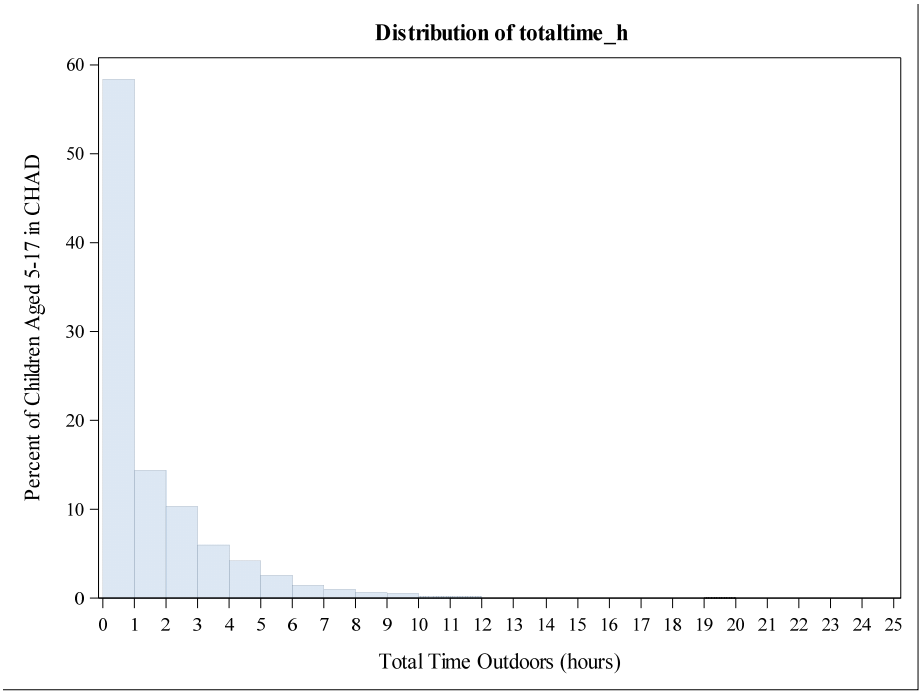
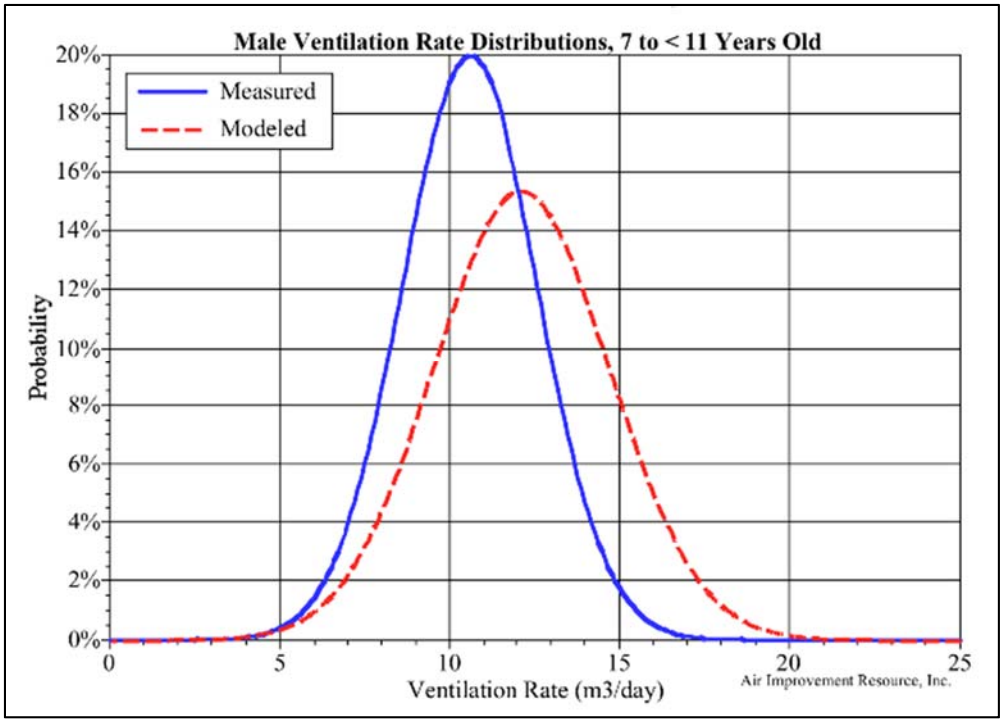


Figure 1. Top Panel: Figure II.1 obtained from API showing "Median Daily Hours APEX-simulated Children Spent Outdoors on Days When They Experienced FEV1 Decrements > 10% (Blue) and > 15% (Red). This figure models base air quality for Los Angeles in 2006 and is restricted to children who experienced two or more lung function decrements in 2006." **Bottom Panel:** The distribution of total daily time spent outdoors calculated here using CHAD diary days for children ages 5-17 (n=15,832).



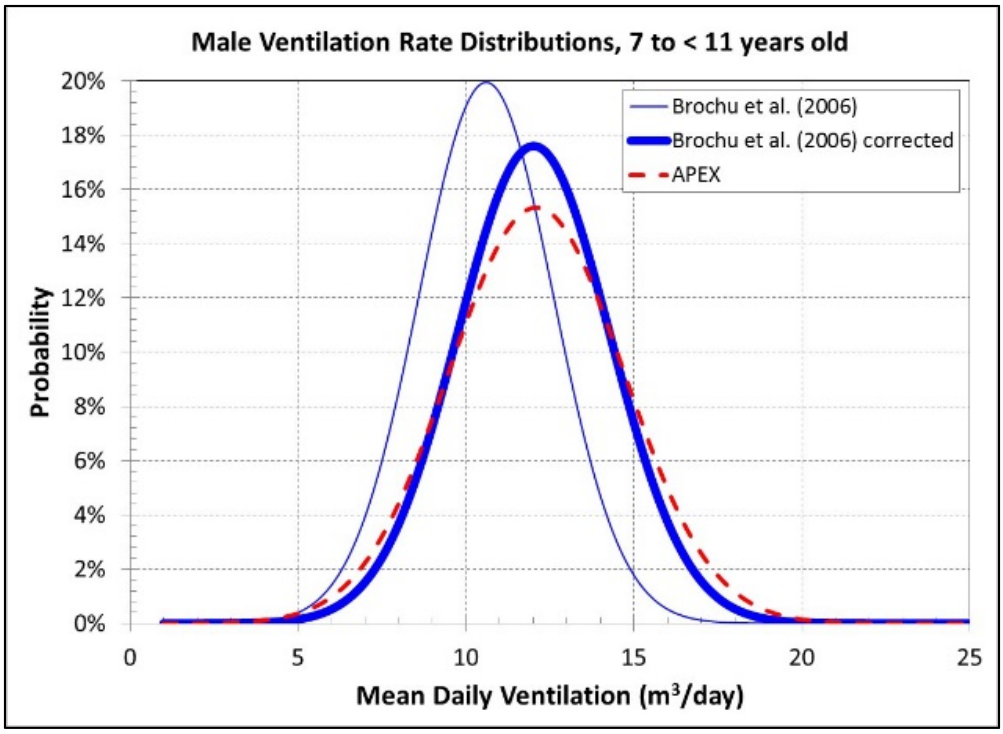
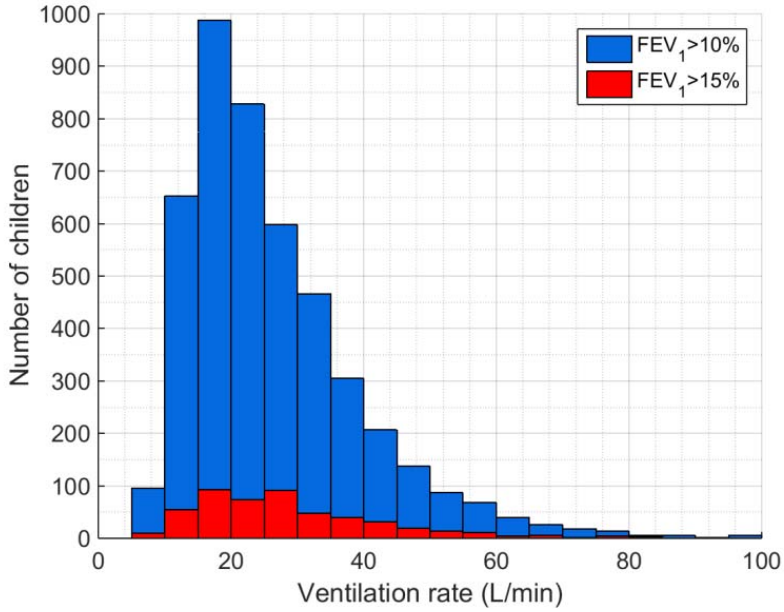


Figure 2. Distributions of mean daily ventilation rates (m3/day) for males ages 7-10 using the APEX model and values reported by Brochu et al., (2006). **Top Panel:** Figure obtained from Alliance of Automobile Manufacturers (AAM) (DCN 2066). **Bottom Panel:** Figure developed for this updated comment response using Brochu et al. (2006) reported and corrected ventilation rates.



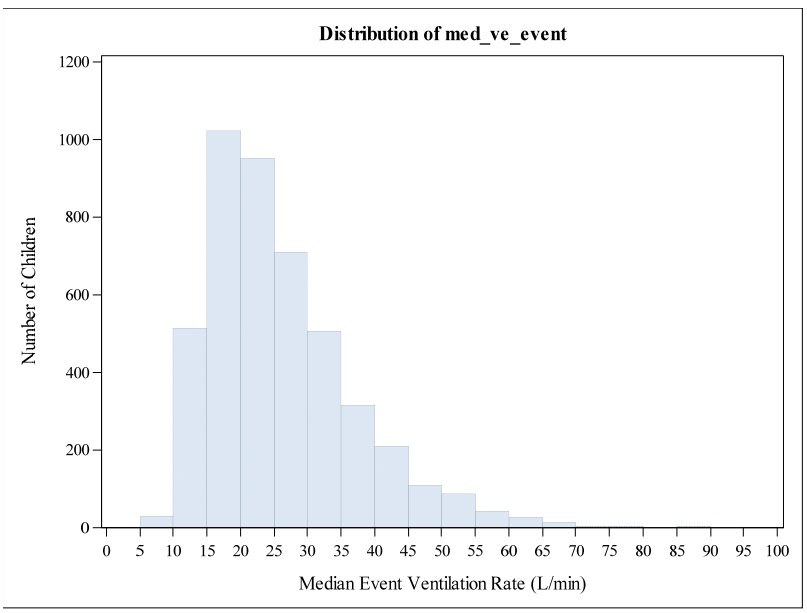


Figure 3. Top Panel: Figure II.2 obtained from API showing "Median Ventilation Rates of APEX-simulated Children on Days When They Experienced FEV1 Decrements >10% (Blue) and > 15% (Red). This figure models base air quality for Los Angeles in 2006 and is restricted to children who experienced two or more lung function decrements in 2006." **Bottom Panel:** Results from a new, similar APEX simulation, illustrating the distribution of median ventilation rates of children 5-18 in Los Angeles at the time (event-level) when they experienced their maximum FEV1 decrement > 10%. Note, the event level ventilation rates vary in duration for the APEX simulated individuals and range from 2 to 60 minutes.

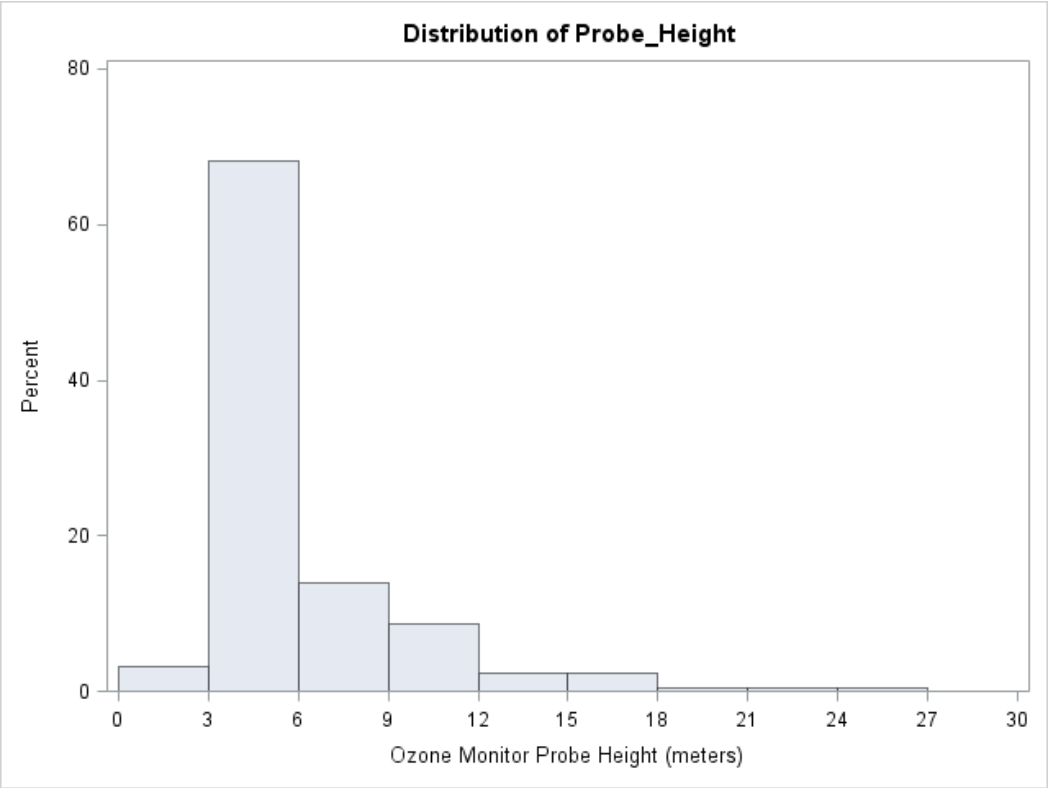


Figure 4. Distribution of ozone monitor probe heights (in meters) for the monitors used to inform ambient concentrations in the 15 O_3 HREA exposure study areas. For purposes of this this presentation, this figure does not include the two monitors where probe height exceeded 30 meters (monitor ID 060595001, 82 meters; ID 170310042, 365 meters).

4. References

Arcus-Arth, A.; J. Blaisdell. 2007. Statistical distributions of daily breathing rates for narrow age groups of infants and children. *Risk Analysis*. 27(1):97-110.

Brochu, P.; J.F. Ducre-Robitaille and J. Brodeur. 2006. Physiological daily inhalation rates for free-living individuals aged 1 month to 96 years, using data from doubly labeled water measurements: a proposal for air quality criteria, standard calculations and health risk assessment. *Human and Ecological Risk Assessment*. 12:675-701.

Graham, S.E.; T. McCurdy. 2005. Revised Ventilation Rate (VE) Equations for Use in Inhalation-oriented Exposure Models. Washington, DC: EPA Office of Air and Radiation. (EPA document number EPA/600/X-05/008, Appendix A). <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=202543>.

Isaacs, K.; G. Glen; T. McCurdy; L. Smith. 2008. Modeling energy expenditure and oxygen consumption in human exposure models: accounting for fatigue and EPOC. *Journal of Exposure Science and Environmental Epidemiology*. 18:289-298.

Johnson, T.; J. Capel; M. McCoy. 1996. Estimation of Ozone Exposures Experienced by Urban Residents using a Probabilistic Version of NEM and 1990 Population Data. Prepared for US EPA/OAQPS by International Technology Air Quality Services. Available at: http://www3.epa.gov/ttn/naaqs/standards/ozone/s_o3_1997.html.

Johnson, T. 1997. A pilot study in Los Angeles to measure personal ozone exposures during scripted activities. Washington, DC: American Petroleum Institute, Health and Environmental Sciences Department; API publication no. DR 218.

Johnson, T. 2002. A Guide to Selected Algorithms, Distributions, and Databases Used in Exposure Models Developed by the Office of Air Quality Planning and Standards. Revised Draft. Prepared for U.S. Environmental Protection Agency under EPA Grant No. CR827033. Available at: http://www2.epa.gov/fera/guide-selected-algorithms-distributions-and-databases-used-exposure-models-developed-office-air.

Johnson, T. 2003. A Guide to Selected Algorithms, Distributions, and Databases Used in Exposure Models Developed by the Office of Air Quality Planning and Standards. Revised Draft Appendices. Prepared for U.S. Environmental Protection Agency under EPA Grant No. CR827033. Available at: http://www2.epa.gov/fera/guide-selected-algorithms-distributions-and-databases-used-exposure-models-developed-office-air.

Langstaff, J.E. 2007. Analysis of Uncertainty in Ozone Population Exposure Modeling, OAQPS Staff Memorandum to Ozone NAAQS Review, January 31. Washington, DC: Office of Air Radiation. (EPA docket number OAR-2005-0172). Available at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_O3_cr_td.html

LeMura L.M.; S.P. Von Duvillard. 2004. Clinical Exercise Physiology: Application and Physiological Principles (e.g., see Figure 30.4, panel 6). Lippincott Williams & Wilkins, Philadelphia, PA.

McArdle W.D.; F.I. Katch; V.L. Katch. (2001). Exercise Physiology. Energy, Nutrition, and Human Performance. 5th edition, Lippincott Williams & Wilkins, Philadelphia, PA.

U.S. EPA. 2006. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF. Available at: http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=149923.

U.S. EPA. 2011. Exposure Factors Handbook 2011 Edition (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011. Available at: http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252.

U.S. EPA. 2012a. Total Risk Integrated Methodology (TRIM) - Air Pollutants Exposure Model Documentation (TRIM.Expo / APEX, Version 4.4) Volume I: User's Guide. Research Triangle Park, NC: EPA Office of Air Quality Planning and Standards. (EPA document number EPA-452/B-12-001a). Available at: http://www.epa.gov/ttn/fera/human_apex.html.

U.S. EPA. 2012b. Total Risk Integrated Methodology (TRIM) - Air Pollutants Exposure Model Documentation (TRIM.Expo / APEX, Version 4.4) Volume II: Technical Support Document. Research Triangle Park, NC: EPA Office of Air Quality Planning and Standards. (EPA document number EPA-452/B-12-001b). Available at: http://www.epa.gov/ttn/fera/human_apex.html.

U.S. EPA. 2013. Integrated Science Assessment of Ozone and Related Photochemical Oxidants (ISA). Research Triangle Park, NC: EPA National Center for Environmental Assessment. (EPA document number EPA 600/R-10/076F). Available at: http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492#Download.

U.S. EPA. 2014. Health Risk and Exposure Assessment for Ozone (HREA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-452/P-14-004a. Available at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_index.html.

Väkevä, M.; K. Hämeri; M. Kulmala; R. Lahdes; J. Ruuskanen; T. Laitinen. 1999. Street level versus rooftop concentrations of submicron aerosol particles and gaseous pollutants in an urban street canyon. *Atmospheric Environment*. 33:1385-1397.