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6 INHALATION RATES

6.1 INTRODUCTION

Ambient and indoor air are potential sources of children's exposure to toxic substances. Children can be exposed to contaminated air during a variety of activities in different environments. Children may be exposed due to sources that contribute pollution to ambient air. Children may also inhale chemicals from the indoor use of various consumer products. Due to their size, physiology, and activity level, the inhalation rates of children differ from those of adults.

Infants and children have a higher resting metabolic rate and oxygen consumption rate per unit of body weight than adults, because of their rapid growth and relatively larger lung surface area per unit of body weight that requires cooling. For example, the oxygen consumption rate for a resting infant between one week and one year of age is 7 milliliters per kilogram of body weight (mL/kg) per minute, while the rate for an adult under the same conditions is 3-5 mL/kg per minute (WHO, 1986). Thus, while greater amounts of air and pollutants are inhaled by adults than children over similar time periods on an absolute basis, the volume of air passing through the lungs of a resting infant is up to twice that of a resting adult on a body weight basis.

The Agency defines exposure as the chemical concentration at the boundary of the body (U.S. EPA, 1992). In the case of inhalation, the situation is complicated by the fact that oxygen exchange with carbon dioxide takes place in the distal portion of the lung. The anatomy and physiology of the respiratory system as well as the characteristics of the inhaled agent diminishes the pollutant concentration in inspired air (potential dose) such that the amount of a pollutant that actually enters the body through the lung (internal dose) is less than that measured at the boundary of the body. A detailed discussion of this concept can be found in *Guidelines for Exposure Assessment* (U.S. EPA, 1992). When constructing risk assessments that concern the inhalation route of exposure, one must be aware of any adjustments that have been employed in the estimation of the pollutant concentration to account for this reduction in potential dose.

Children's inhalation dosimetry and health effects were topics of discussion at a U.S. EPA workshop held in June 2006 (Foos and Sonawane, 2008). Age related differences in lung structure and function, breathing patterns, and how these affect the inhaled dose and the deposition of particles in the lung are important factors in assessing risks from inhalation exposures (Foos et al., 2008). Children may have a lesser nasal contribution to breathing during rest and while performing various activities. The uptake of particles in the nasal airways is also less efficient in children. Thus, the deposition of particles in the lower respiratory tract may be greater (Foos et al., 2008).

Inclusion of this chapter in the Child-Specific Exposure Factors Handbook does not imply that assessors will always need to select and use inhalation rates when evaluating exposure to air contaminants. For example, it is unnecessary to calculate inhaled dose when using dose-response factors from the Integrated Risk Information System (IRIS) (U.S. EPA, 1994), because the IRIS methodology accounts for inhalation rates in the development of "dose-response" relationships. Information in this chapter may be used by toxicologists in their derivation of human equivalent concentrations. When using IRIS for inhalation risk assessments, "dose-response" relationships require only an average air concentration to evaluate health concerns:

- For non-carcinogens, IRIS uses Reference Concentrations (RfCs) which are expressed in concentration units. Hazard is evaluated by comparing the inspired air concentration to the RfC.
- For carcinogens, IRIS uses unit risk values which are expressed in inverse concentration units. Risk is evaluated by multiplying the unit risk by the inspired air concentration.

Detailed descriptions of the IRIS methodology for derivation of inhalation reference concentrations can be found in two methods manuals produced by the Agency (U.S. EPA, 1992; 1994).

The Superfund Program has also updated its approach for determining inhalation risk, eliminating the use of inhalation rates when evaluating exposure to air contaminants (U.S. EPA, 2008). The current methodology recommends that risk assessors use the concentration of the chemical in air as the exposure metric (e.g., mg/m^3), instead of the intake of a contaminant in air based on inhalation rate and body weight (e.g., mg/kg-day).

Recommended inhalation rates (both long- and short-term) are provided in the next section, along with the confidence ratings for these recommendations. These recommendations are based on four key studies identified by U.S. EPA for this factor. Long-term exposure is repeated exposure for more than 30 days, up to approximately 10% of the life span in humans (more than 30 days). Long-term inhalation rates for children (including infants) are presented as daily rates (m^3/day). Short-term exposure is repeated exposure for more than 24 hours, up to 30 days. Short-term inhalation rates are reported for children (including infants) performing various activities in m^3/minute. Following the recommendations, the available studies (both key and relevant studies) on inhalation rates are summarized.

6.2 RECOMMENDATIONS

The recommended inhalation rates for children are based on four recent studies: Brochu et al., 2006; U.S. EPA, 2006; Arcus-Arth and Blaisdell, 2007; and Stifelman, 2007. These studies represent an improvement upon those previously used for recommended inhalation rates in this handbook, because they use a large data set that is representative of the United States as a whole and consider the correlation between body weight and inhalation rate.

The selection of inhalation rates to be used for exposure assessments depends on the age of the exposed population and the specific activity levels of this population during various exposure scenarios. The recommended long-term values for children (including infants) for use in various exposure scenarios are presented in Table 6-1 for the standard U.S. EPA childhood age groups used in this handbook. As shown in Table 6-1, the daily average inhalation rates for long-term exposures for male and female children combined (unadjusted for body weight) range from 3.6 m^3/day for children from birth to <1 month to 16.5 m^3/day for children aged 16 to <21 years. These values represent averages of the inhalation rate data from the four key studies. The 95^{th} percentile values range from 7.1 m^3/day to 27.6 m^3/day for the same age categories. The 95^{th} percentile values represent averages of the inhalation rate data from the three key studies for which 95^{th} percentile values were available for selected age groups (Brochu et al., 2006; U.S. EPA, 2006; Arcus-Arth and Blaisdell, 2007). It should be noted that there may be a high degree of uncertainty associated with the upper percentiles. These values equate to unusually high estimates of caloric intake per day, and are unlikely to be representative of the average child. For example, using Layton's equation (Layton, 1993) for estimating metabolically consistent inhalation rates to calculate caloric equivalence (see Section 6.4.6), the 95^{th} percentile value for 16 to <21 year old children is 4,840 kcal/day. All of the 95^{th} percentile values listed in Table 6-1 may represent unusually high inhalation rates for long-term exposures, even for the upper end of the distribution, but were included in this handbook to provide exposure assessors a sense of the possible range of inhalation rates for children. These values should be used with caution when estimating long-term exposures.

For short-term exposures for children aged 21 years and under, for which activity patterns are known, mean and 95^{th} percentile data are provided in Table 6-2 for males and females combined, in m^3/minute. These values represent averages of the activity level data from the one key study from which short-term inhalation rate data were available (U.S. EPA, 2006).

The confidence ratings for the inhalation rate recommendations are shown in Table 6-3. Multiple percentiles for long- and short-term inhalation rates for both males and females are provided in Tables 6-5 through 6-11 and Table 6-16.

Table 6-1. Recommended Long-Term Exposure (More Than 30 Days) Values for Inhalation (Males and Females Combined).

Age Group	Mean m^3/day	Sources Used for Means	95th Percentile m^3/day	Sources Used for 95th Percentiles	Multiple Percentiles
Birth to <1 month	3.6	a	7.1	a	
1 to <3 months	- [b]	-	-	-	
3 to <6 months	4.1	a,c	6.1	a,c	
6 to <12 months	5.4	a,c	8.1	a,c	
1 to <2 years	8.0	a,c,d,e	12.8	a,c,d	See Tables 6-5 through 6-11 and 6-16
2 to <3 years	9.5	a,d,e	15.9	a,d	
3 to <6 years	10.9	a,d,e	16.2	a,d	
6 to <11 years	12.4	a,d,e	18.7	a,d	
11 to <16 years	15.1	a,d,e	23.5	a,d	
16 to <21 years	16.5	a,d,e	27.6	a,d	

[a] Arcus-Arth and Blaisdell, 2007.
[b] No data for this age group.
[c] Brochu et al., 2006.
[d] U.S. EPA, 2006.
[e] Stifelman, 2007.
Note: Some 95th percentile values may be unusually high, and may not be representative of the average child.

Table 6-2. Recommended Short-Term Exposure (Less Than 30 Days) Values for Inhalation (Males and Females Combined)

Activity Level	Age Group years	Mean m^3/minute	95th Percentile m^3/minute	Multiple Percentiles
Sleep or Nap	Birth to <1 year	3.0E-03	4.6E-03	
	1 to <2 years	4.5E-03	6.4E-03	
	2 to <3 years	4.6E-03	6.4E-03	
	3 to <6 years	4.3E-03	5.8E-03	
	6 to <11 years	4.5E-03	6.3E-03	
	11 to <16 years	5.0E-03	7.4E-03	
	16 to <21 years	4.9E-03	7.1E-03	
Sedentary/ Passive	Birth to <1 year	3.1E-03	4.7E-03	
	1 to <2 years	4.7E-03	6.5E-03	
	2 to <3 years	4.8E-03	6.5E-03	
	3 to <6 years	4.5E-03	5.8E-03	
	6 to <11 years	4.8E-03	6.4E-03	
	11 to <16 years	5.4E-03	7.5E-03	
	16 to <21 years	5.3E-03	7.2E-03	
Light Intensity	Birth to <1 year	7.6E-03	1.1E-02	See Tables 6-11 and 6-12
	1 to <2 years	1.2E-02	1.6E-02	
	2 to <3 years	1.2E-02	1.6E-02	
	3 to <6 years	1.1E-02	1.4E-02	
	6 to <11 years	1.1E-02	1.5E-02	
	11 to <16 years	1.3E-02	1.7E-02	
	16 to <21 years	1.2E-02	1.6E-02	
Moderate Intensity	Birth to <1 year	1.4E-02	2.2E-02	
	1 to <2 years	2.1E-02	2.9E-02	
	2 to <3 years	2.1E-02	2.9E-02	
	3 to <6 years	2.1E-02	2.7E-02	
	6 to <11 years	2.2E-02	2.9E-02	
	11 to <16 years	2.5E-02	3.4E-02	
	16 to <21 years	2.6E-02	3.7E-02	
High Intensity	Birth to <1 year	2.6E-02	4.1E-02	
	1 to <2 years	3.8E-02	5.2E-02	
	2 to <3 years	3.9E-02	5.3E-02	
	3 to <6 years	3.7E-02	4.8E-02	
	6 to <11 years	4.2E-02	5.9E-02	
	11 to <16 years	4.9E-02	7.0E-02	
	16 to <21 years	4.9E-02	7.3E-02	

Source: U.S. EPA, 2006.

Table 6-3. Confidence in Recommendations for Inhalation Rates

General Assessment Factors	Rationale	Rating
Soundness		Medium
Adequacy of Approach	The survey methodology and data analysis was adequate. Measurements were made by indirect methods. The studies analyzed existing primary data.	
Minimal (or defined) Bias	Potential bias within the studies was fairly well documented.	
Applicability and Utility		High
Exposure Factor of Interest	The studies focused on inhalation rates and factors influencing them.	
Representativeness	The studies focused on the U.S. population. A wide range of age groups were included.	
Currency	The studies were published during 2006 and 2007 and represent current exposure conditions.	
Data Collection Period	The data collection period for the studies may not be representative of long-term exposures.	
Clarity and Completeness		Medium
Accessibility	All key studies are available from the peer reviewed literature.	
Reproducibility	The methodologies were clearly presented; enough information was included to reproduce most results.	
Quality Assurance	Information on ensuring data quality in the key studies was limited.	
Variability and Uncertainty		Medium
Variability in Population	In general, the key studies addressed variability in inhalation rates based on age and activity level. However, other factors that may affect inhalation rates (e.g., weight, body mass index [BMI], ethnicity) are not discussed.	
Uncertainty	Multiple sources of uncertainty exist for these studies. Assumptions associated with Energy Expenditure (EE) based estimation procedures are a source of uncertainty in inhalation rate estimates.	
Evaluation and Review		High
Peer Review	Three of the key studies appeared in peer reviewed journals, and one key study is a U.S. EPA peer reviewed report.	
Number and Agreement of Studies	There are four key studies. The results of studies from different researchers are in general agreement.	
Overall Rating		**Medium**

6.3 KEY INHALATION RATE STUDIES

6.3.1 Brochu et al., 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

Brochu et al. (2006) calculated physiological daily inhalation rates (PDIR) for 2,210 individuals aged 3 weeks to 96 years using the reported disappearance rates of oral doses of doubly labeled water (DLW) (^2H_2O and $H_2{}^{18}O$) in urine, monitored by gas-isotope-ratio mass spectrometry for an aggregate period of more than 30,000 days. DLW data were complemented with indirect calorimetry and nutritional balance measurements.

In the DLW method, the disappearance of the stable isotopes deuterium (^2H) and heavy oxygen-18 (^{18}O) are monitored in urine, saliva, or blood samples over a long period of time (from 7 to 21 days) after subjects receive oral doses of ^2H_2O and $H_2{}^{18}O$. The disappearance rate of ^2H reflects water output and that of ^{18}O represents water output plus carbon dioxide (CO_2) production rates. The CO_2 production rate is then calculated by difference between the two disappearance rates. Total daily energy expenditures (TDEEs) are determined from CO_2 production rates using classic respirometry formulas, in which values for the respiratory quotient ($RQ = CO_{2\,produced}/O_{2\,consumed}$) are derived from the composition of the diet during the period of time of each study. The DLW method also allows for measurement of the energy cost of growth (ECG). TDEE and ECG measurements can be converted into PDIR values using the following equation developed by Layton (1993):

$$PDIR = (TDEE + ECG) \times H \times VQ\ 10^{-3} \qquad \text{(Eqn. 6-1)}$$

where:

PDIR = physiological daily inhalation rates (m^3/day);
TDEE = total daily energy expenditure (kcal/day);
ECG = stored daily energy cost for growth (kcal/day);
H = oxygen uptake factor, volume of 0.21 L of oxygen (at standard temperature and pressure, dry air) consumed to produce 1 kcal of energy expended;
VQ = ventilatory equivalent ratio of the minute volume (V_E) at body temperature pressure saturation) to the oxygen uptake rate (VO_2 at standard temperature and pressure, dry air) $V_E/VO_2 = 27$; and
10^{-3} = conversion factor (L/m^3).

Brochu et al. (2006) calculated daily inhalation rates (expressed in m^3/day and m^3/kg-day) for a variety of age groups and physiological conditions. Published data on BMI, body weight, basal metabolic rate (BMR), ECG, and TDEE measurements (based on DLW method and indirect calorimetry) for subjects aged 2.6 months to 96 years were used. Only the data for children are presented in this handbook. Data for underweight, healthy normal-weight, and overweight/obese individuals were gathered and defined according to BMI cutoffs. Data for newborns were included regardless of BMI values, because they were clinically evaluated as being healthy infants.

Mean inhalation rates for newborns are presented in Table 6-4. Due to the insufficient number of subjects, no distributions were derived for this group. The distribution of daily inhalation rates for normal-weight and overweight/obese individuals by gender and age groups are presented in Tables 6-5 to 6-9.

An advantage of this study is that data are provided for age groups of less than one year. A limitation of this study is that data for individuals with pre-existing medical conditions was lacking.

6.3.2 U.S. EPA, 2006 - Metabolically-derived Human Ventilation Rates: A Revised Approach Based Upon Oxygen Consumption Rates

U.S. EPA (2006) conducted a study to ascertain inhalation rates for children and adults. Specifically, U.S. EPA sought to improve upon the methodology used by Layton (1993) and other studies that relied upon the ventilatory equivalent (VQ) and a linear relationship between oxygen consumption and fitness rate. A revised approach, developed by U.S. EPA's National Exposure Research Laboratory (NERL), was used, in which an individual's inhalation rate was derived from his or her assumed oxygen consumption rate. U.S. EPA applied this revised approach using body weight data from the 1999-2002 National Health and Nutrition Examination Survey (NHANES) and metabolic equivalents (METS) data from U.S. EPA's Consolidated Human Activity Database (CHAD). In this database, metabolic cost is given in units of "METS" or "metabolic equivalents of work," an energy expenditure metric used by exercise physiologists and clinical nutritionists to represent activity levels. An activity's METS value represents a dimensionless ratio of its metabolic rate (energy expenditure) to a person's resting, or basal metabolic rate (BMR).

NHANES provided age, gender, and body weight data for 19,022 individuals from throughout the United States. From these data, basal metabolic rate (BMR) was estimated using an age-specific linear equation used in the Exposure Factors Handbook (U.S. EPA, 1997), and in several other studies and reference works.

The CHAD database is a compilation of several databases of human activity patterns. U.S. EPA used one of these studies, the National Human Activity Pattern Survey (NHAPS), as its source for METS values because it was more representative of the entire United States population than the other studies in the database. The NHAPS data set included activity data for 9,196 individuals, each of which provided 24 hours of activity pattern data using a diary-based questionnaire. While NHAPS was identified as the best available data source for activity patterns, there were some shortcomings in the quality of the data. Study respondents did not provide body weights; instead, body weights are simulated using statistical sampling. Also, the NHAPS data extracted from CHAD could not be corrected to account for non-random sampling of study participants and survey days.

NHANES and NHAPS data were grouped into age categories using the standardized age categories presented elsewhere in this handbook, with the exception that children under the age of one year were placed into a single category to preserve an adequate sample size within the category. For each NHANES participant, a "simulated" 24-hour activity pattern was generated by randomly sampling activity patterns from the set of NHAPS participants with the same gender and age category as the NHANES participant. Twenty such patterns were selected at random for each NHANES participant, resulting in 480 hours of simulated activity data for each NHANES participant. The data were then scaled down to a 24-hour time frame to yield an average 24-hour activity pattern for each of the 19,022 NHANES individuals.

Each activity was assigned a METS value based on statistical sampling of the distribution assigned by CHAD to each activity code. For most codes, these distributions were not age-dependent, but age was a factor for some activities for which intensity level varies strongly with age. Using statistical software, equations for METS based on normal, lognormal, exponential, triangular, and uniform distributions were generated as needed for the various activity codes. The METS values were then translated into energy expenditure (EE) by multiplying the METS by the basal metabolic rate (BMR), which was calculated as a linear function of body weight. The oxygen consumption rate (VO_2) was calculated by multiplying EE by H, the volume of oxygen consumed per unit of energy. VO_2 was calculated both as volume per time and as volume per time per unit body weight.

The inhalation rate for each activity within the 24-hour simulated activity pattern for each individual was estimated as a function of VO_2, body weight, age, and gender. Following this, the average inhalation rate was calculated for each individual for the entire 24-hour period, as well as for four separate classes of activities based on METS value (sedentary/passive (METS less than or equal to 1.5), light intensity (METS greater than 1.5 and less than or equal to 3.0), moderate intensity (METS greater than 3.0 and less than or equal to 6.0), and high intensity (METS greater than 6.0). Data for individuals were then used to generate summary tables based on gender and age categories.

Data from this study are presented in Tables 6-10 through 6-15. Tables 6-10 and 6-11 present, for male and female subjects, respectively, summary statistics for daily average inhalation rate by age category on a volumetric (m^3/day) and body-weight adjusted (m^3/day-kg) basis. Table 6-12 presents the mean and 95th percentile values for males, females, and males and females combined. Tables 6-13 and 6-14 present, for male and female subjects, respectively, mean ventilation rates by age category on a volumetric (m^3/min) and body-weight adjusted (m^3/min-kg) basis for the five different activity level ranges described above. Table 6-15 presents the number of hours spent per day at each activity level by males and females.

An advantage of this study is the large sample size. In addition, the datasets used, NHAPS and NHANES, are representative of the U.S. general population. Limitations are that the NHAPS data are 10 years old, there is variability in the 24-hour activity, and there is uncertainty in the METs randomization, all of which were noted by the authors.

6.3.3 Arcus-Arth and Blaisdell, 2007 - Statistical Distributions of Daily Breathing Rates for Narrow Age Groups of Infants and Children

Arcus-Arth and Blaisdell (2007) derived daily breathing rates for narrow age ranges of children using the metabolic conversion method of Layton (1993) and energy intake data adjusted to represent the U.S. population from the Continuing Survey of Food Intake for Individuals (CSFII) 1994-1996, 1998. Normalized (m^3/kg-day) and nonnormalized (m^3/day) breathing rates for children 0-18 years of age were derived using the general equation developed by Layton (1993) to calculate energy-dependent inhalation rates (see Equation 6-2).

$$VE = H \times VQ \times EE \qquad \text{(Eqn. 6-2)}$$

where:

VE = volume of air breathed per day (m^3/day);
H = volume of oxygen consumed to produce 1 kcal of energy (m3/kcal);
VQ = ratio of the volume of air to the volume of oxygen breathed per unit time (unitless); and
EE = energy (kcal) expended per day.

Arcus-Arth and Blaisdell (2007) calculated H values of 0.22 and 0.21 for infants and noninfant children, respectively, using the 1977-1978 NFCS and CSFII data sets. Ventilatory equivalent (VQ) data, including those for infants, were obtained from 13 studies that reported VQ data for children aged 4-8 ears. Separate preadolescent (4-8 years) and adolescent (9-18 years) VQ values were calculated in addition to separate VQ values for adolescent boys and girls. Two-day-averaged daily energy intake (EI) values reported in the CSFII data set were used a surrogate for EE. CSFII records that did not report body weight and those for children who consumed breast milk or were breast fed were excluded from their analyses. The EIs of children 9 years of age and older were multiplied by 1.2, the value calculated by Layton (1993) to adjust for potential bias related to underreporting of dietary intakes by older children. For infants, EI values were adjusted by subtracting the amount of energy put into storage by infants as estimated by Scrimshaw et al. (1996). Self-reported body weights for each individual from the CSFII data set were used to calculate nonnormalized (m^3/day) and normalized (m^3/kg-day) breathing rates, which decreased the variability in the resulting breathing rate data. Daily breathing rates were grouped into three-month age groups for infants, one-year age groups for children 1-18 years of age, and the age groups recommended by U.S. EPA cancer guidelines supplement (U.S. EPA, 2005) to receive greater weighting for mutagenic carcinogens (0 to < 2 years of age, and 2 to < 16 years of age). Data were also presented for adolescent boys and girls, aged 9-18 years (Table 6-16). For each age and age-gender group, Arcus-Arth and Blaisdell (2007) calculated the arithmetic mean, standard error of the mean, percentiles (50^{th}, 90^{th}, and 95^{th}), geometric mean, standard deviation, and best-fit parametric models of the breathing rate distributions. Overall, the CSFII-derived nonnormalized breathing rates progressively increased with age from infancy through 18 years of age, while normalized breathing rates progressively decreased. The data are presented in Table 6-16 in units of m^3/day. There were statistical differences between boys and girls 9-18 years of age, both for these years combined ($p < 0.00$) and for each year of age separately ($p < 0.05$). The authors reasoned that since the fat-free mass (basically muscle mass) of boys typically increases during adolescence, and because fat-free mass is highly correlated to basal metabolism which accounts for the majority of EE, nonnormalized breathing rates for adolescent boys may be expected to increase with increasing age. Table 6-17 presents the mean and 95th percentile values for males and females combined, averaged to fit within the standard EPA age groups.

The CSFII-derived mean breathing rates derived by Arcus-Arth and Blaisdell (2007) were compared to the mean breathing rates estimated in studies that utilized doubly labeled water (DLW) technique EE data that had been coupled with the Layton (1993) method. The infants' CSFII-derived breathing rates were 15 to 27 percent greater than the comparison DLW EE breathing rates while the children's CSFII rates ranged from 23 percent less to 14 percent greater than comparison rates. Thus, the CSFII and comparison rates were quite similar across age groups.

An advantage of this study is that it provides breathing rates specific to narrow age ranges, which can be useful for assessing inhalation dose during periods of greatest susceptibility. However, the study is limited by the potential for misreporting, underestimating, or overestimating of food intake data in the CSFII. In addition to underreporting of food intake by adolescents, EI values for younger children may be under- or overestimated. Overweight children (or their parents) may also underreport food intakes. In addition, adolescents who misreport food intake may have also misreported body weights.

6.3.4 Stifelman, 2007 - Using Doubly-labeled Water Measurements of Human Energy Expenditure to Estimate Inhalation Rates

Stifelman (2007) estimated inhalation rates using DLW energy data. The DLW method administers two forms of stable isotopically labeled water: deuterium-labeled (^2H_2O) and ^{18}oxygen-labeled ($H_2{}^{18}O$). The difference in disappearance rates between the two isotopes represents the energy expended over a period of 1–3 half-lives of the labeled water (Stifelman, 2007). The resulting duration of observation is typically 1–3 weeks, depending on the size and activity level.

The DLW database contains subjects from areas around the world and represents diversity in ethnicity, age, activity, body type, and fitness level. DLW data have been compiled by the Institute of Medicine (IOM) Panel on Macronutrients and the Food and Agriculture Organization of the United Nations (FAO). Stifelman (2007) used the equation of Layton (1993) to convert the recommended energy levels of IOM for the active-very active people to their equivalent inhalation rates. The IOM reports recommend energy expenditure levels organized by gender, age and body size (Stifelman, 2007).

The equivalent inhalation rates are shown in Table 6-18. Shown in Table 6-19 are the mean and 95th percentile values for the IOM "active" energy level category, averaged to fit within the standard EPA age groups. Stifelman (2007) noted that the estimates based on the DLW are consistent with previous findings of Layton (1993) and the Exposure Factors Handbook (U.S. EPA, 1997) and that inhalation rates based on the IOM active classification are consistent with the mean inhalation rate in the handbook.

The advantages of this study are that the inhalation rates were estimated using the DLW data from a large data set. Stifelman (2007) noted that DLW methods are advantageous; the data are robust, measurements are direct and avoid errors associated with indirect measurements (heart rate), subjects are free-living, and the period of observation is longer than what is possible from staged activity measures. Observations over a longer period of time reduce the uncertainties associated with using short duration studies to infer long-term inhalation rates. A limitation with the study is that the inhalation rates that are presented are for active/very active persons only.

6.3.5 Key Studies Combined

In order to provide the recommended long-term inhalation rates shown in Table 6-1**,** data from the four key studies were combined. The data from each study were averaged by gender and grouped according to the standard U.S. EPA childhood age groups used in this handbook, when possible. Mean and 95th percentile inhalation rate values for the four key studies are shown in Tables 6-20 and 6-21, respectively.

6.4 RELEVANT INHALATION RATE STUDIES

6.4.1 International Commission on Radiological Protection (ICRP), 1981 - Report of the Task Group on Reference Man

The International Commission on Radiological Protection (ICRP) (1981) estimated daily inhalation rates for reference children (10 years old), infants (1 year old), and newborn babies by using a time-activity-ventilation approach. This approach for estimating an inhalation rate over a specified period of time was based on calculating a time weighted average of inhalation rates associated with physical activities of varying durations (Table 6-22). ICRP (1981) compiled reference values (Table 6-23) of minute volume/inhalation rates from various literature sources. ICRP (1981) assumed that the daily activities of a reference child (10 yrs) consisted of 8 hours of rest and 16 hours of light activities. It was assumed that a day consisted of 14 hours resting and 10 hours light activity for an infant (1 year). A newborn's daily activities consisted of 23 hours resting and 1 hour light activity. The estimated inhalation rates were 14.8 m^3/day for children (age 10 years), 3.76 m^3/day for infants (age 1 year), and 0.78 m^3/day for newborns (Table 6-22).

A limitation associated with this study is that the validity and accuracy of the inhalation rate data used in the compilation of reference values were not specified. This introduces some degree of uncertainty in the results obtained. Also, the approach used required that assumptions be made regarding the hours spent by various age/gender cohorts in specific activities. These assumptions may over/under-estimate the inhalation rates obtained.

6.4.2 U.S. EPA, 1985 - Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments

The U.S. EPA (1985) compiled measured values of minute ventilation for various age/gender cohorts from early studies. The data compiled by the U.S. EPA (1985) for each age/gender cohorts were obtained at various activity levels (Table 6-24). These levels were categorized as light, moderate, or heavy according to the criteria developed by the U.S. EPA Office of Environmental Criteria and Assessment for the Ozone Criteria Document. These criteria were developed for a reference male adult with a body weight of 70 kg (U.S. EPA, 1985).

Table 6-24 presents a summary of inhalation rates by age and activity level. A description of activities included in each activity level is also presented in Table 6-24. Table 6-24 indicates that at rest, the mean inhalation rate for children, ages 6 and 10 years, is 0.4 m^3/hr. Table 6-25 presents activity pattern data aggregated for three microenvironments by activity level for all age groups. The total average hours spent indoors was 20.4, outdoors was 1.77, and in a transportation vehicle was 1.77. Based on the data presented in Tables 6-24 and 6-25, a daily inhalation rate was calculated for adults and children by using a time-activity-ventilation approach. These data are presented for children in Table 6-26. The average daily inhalation rate for 6 and 10 years old children is 16.74 and 21.02 m^3/day, respectively.

Limitations associated with this study are its age and that many of the values used in the data compilation were from early studies. The accuracy and/or validity of the values used and data collection method were not presented in U.S. EPA (1985). This introduces uncertainty in the results obtained. An advantage of this study is that the data are actual measurement data for a large number of children.

6.4.3 Linn et al., 1992 - Documentation of Activity Patterns in "High-risk" Groups Exposed to Ozone in the Los Angeles Area

Linn et al. (1992) conducted a study that estimated the inhalation rates for "high-risk" subpopulation groups exposed to ozone in their daily activities in the Los Angeles area. The population surveyed consisted of several panels of children. The panels included *Panel 2*: 17 healthy elementary school students (5 males and 12 females, ages 10-12 years); *Panel 3*: 19 healthy high school students (7 males and 12 females, ages 13-17 years); *Panel 6*: 13 young asthmatics (7 males and 6 females, ages 11-16 years).

An initial calibration test was conducted, followed by a training session. Finally, a field study that involved the subjects collecting their own heart rates and diary data was conducted. During the calibration tests, ventilation rate (VR), breathing rate, and heart rate (HR) were measured simultaneously at each exercise level. From the calibration data an equation was developed using linear regression analysis to predict VR from measured HR.

In the field study, each subject recorded in diaries their daily activities, change in locations (indoors, outdoors, or in a vehicle), self-estimated breathing rates during each activity/location, and time spent at each activity/location. Healthy subjects recorded their HR once every 60 seconds using a Heart

Watch, an automated system consisting of a transmitter and receiver worn on the body. Asthmatic subjects recorded their diary information once every hour. Subjective breathing rates were defined as slow (walking at their normal pace), medium (faster than normal walking), and fast (running or similarly strenuous exercise). Table 6-27 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 6-28 presents the mean, 99^{th} percentile, and mean VR at each subjective activity level (slow, medium, fast). The mean and 99th percentile VR were derived from all HR recordings that appeared to be valid, without considering the diary data. Each of the three activity levels was determined from both the concurrent diary data and HR recordings by direct calculation or regression. The authors reported that the diary data showed that on a typical day, most individuals spent most of their time indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects (Table 6-28). The authors also reported that in every panel the predicted VR correlated significantly with the subjective estimates of activity levels.

A limitation of this study is that calibration data may overestimate the predictive power of HR during actual field monitoring. The wide variety of exercises in everyday activities may result in greater variation of the VR-HR relationship than was calibrated. Another limitation is the small sample size of each subpopulation surveyed. An advantage of this study is that diary data can provide rough estimates of ventilation patterns which are useful in exposure assessments. Another advantage is that inhalation rates were presented for both healthy and asthmatic children.

6.4.4 Spier et al., 1992 - Activity Patterns in Elementary and High School Students Exposed to Oxidant Pollution

Spier et al. (1992) investigated the activity patterns of 17 elementary school students (10-12 years old) and 19 high school students (13-17 years old) in suburban Los Angeles from late September to October (oxidant pollution season). Calibration tests were conducted in supervised outdoor exercise sessions. The exercise sessions consisted of 5 minutes each of rest, slow walking, jogging, and fast walking. HR and VR were measured during the last 2 minutes of each exercise. Individual VR and HR relationships for each individual were determined by fitting a regression line to HR values and log VR values. Each subject recorded their daily activities, changes in location, and breathing rates in diaries for 3 consecutive days. Self-estimated breathing rates were recorded as slow (slow walking), medium (walking faster than normal), and fast (running). HR was recorded once per minute during the 3 days using a Heart Watch. VR values for each self-estimated breathing rate and activity type were estimated from the HR recordings by employing the VR and HR equation obtained from the calibration tests.

The data presented in Table 6-29 represent HR distribution patterns and corresponding predicted VR for each age group during hours spent awake. At the same self-reported activity levels for both age groups, inhalation rates were higher for outdoor activities than for indoor activities. The total number of hours spent indoors was higher for high school students (21.2 hours) than for elementary school students (19.6 hours). The converse was true for outdoor activities: 2.7 hours for high school students and 4.4 hours for elementary school students (Table 6-30).

A limitation of this study is the small sample size. The results may not be representative of all children in these age groups. Another limitation is that the accuracy of the self-estimated breathing rates reported by younger age groups is uncertain. This may affect the validity of the data set generated. An advantage of this study is that inhalation rates were determined for children and adolescents. These data are useful in estimating exposure for the younger population.

6.4.5 Adams, 1993 - Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities, Final Report

Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/gender cohorts and specific activities, and (2) derivation of simple linear and multiple regression equations that could be used to predict inhalation rates through other measured variables: breathing frequency and oxygen consumption. A total of 160 subjects participated in the primary study. For children, there were two age-dependent groups: children 6 to 12.9 years old and adolescents 13 to18.9 years old. An additional 40 children from 6 to 12.9 years old and 12 young children from 3 to 5.9 years old were identified as subjects for pilot testing purposes.

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. The phases were categorized as resting and sedentary activities. Two active protocols— moderate (walking) and heavy (jogging/ running) phases— were performed on a treadmill over a progressive continuum of intensity levels made up of 6-minute intervals at three speeds ranging from slow to moderately fast. All protocols involved measuring VR, HR, f_B (breathing frequency), and VO_2 (oxygen consumption). Measurements were taken in the last 5 minutes of each phase of the resting protocol and the last 3 minutes of the 6-minute intervals at each speed designated in the active protocols.

In the field, all children completed spontaneous play protocols; most protocols were conducted for 30 minutes. All the active field protocols were conducted twice. Results are shown in Tables 6-31 and 6-32.

During all activities in either the laboratory or field protocols, VR for the children's group revealed no significant gender differences. Therefore, VR data presented in Tables 6-33 and 6-34 were categorized by activity type (lying, sitting, standing, walking, and running) for young children and children without regard to gender. These categorized data from Tables 6-33 and 6-32 are summarized as inhalation rates in Tables 6-31 and 6-32. The laboratory protocols are shown in Table 6-31. Table 6-32 presents the mean inhalation rates by group and for moderate activity levels in field protocols. Data were not provided for the light and sedentary activities because the group did not perform for this protocol or the number of subjects was too small for appropriate comparisons. Accurate predictions of inhalation rates across all population groups and activity types were obtained by including body surface area (SA), HR, and breathing frequency in multiple regression analysis (Adams, 1993). Adams (1993) calculated SA from measured height and body weight using the equation:

$$SA = Height^{(0.725)} \times Weight^{(0.425)} \times 71.84 \quad \text{(Eqn. 6-3)}$$

A limitation associated with this study is that the population does not represent the general U.S. population. Also, the classification of activity types (i.e., laboratory and field protocols) into activity levels may bias the inhalation rates obtained for various age/gender cohorts. The estimated rates were based on short-term data and may not reflect long-term patterns.

6.4.6 Layton, 1993 - Metabolically Consistent Breathing Rates for Use in Dose Assessments

Layton (1993) presented a method for estimating metabolically consistent inhalation rates for use in quantitative dose assessments of airborne radionuclides. Generally, the approach for estimating the breathing rate for a specified time frame was to calculate a time-weighted-average of ventilation rates associated with physical activities of varying durations. However, in this study, breathing rates were calculated on the basis of oxygen consumption associated with energy expenditures for short (hours) and long (weeks and months) periods of time, using the following general equation to calculate energy-dependent inhalation rates:

$$V_E = E \times H \times VQ \quad \text{(Eqn. 6-4)}$$

where:

V_E = ventilation rate (m^3/min or m^3/day);
E = energy expenditure rate; [kilojoules/minute (KJ/min) or megajoules/hour (MJ/hr)];
H = volume of oxygen (at standard temperature and pressure, dry air consumed in the production of 1 kilojoule (KJ) of energy expended (L/KJ or m^3/MJ)); and
VQ = ventilatory equivalent (ratio of minute volume (m^3/min) to oxygen uptake (m^3/min)) unitless.

Layton (1993) used two alternative approaches to estimate daily chronic (long term) inhalation rates for different age/gender cohorts of the U.S. population using this methodology.

First Approach

Inhalation rates were estimated by multiplying average daily food energy intakes for different age/gender cohorts, H, and VQ, as shown in the equation above. The average food energy intake data (Table 6-35) are based on approximately 30,000 individuals and were obtained from the 1977-78 USDA-NFCS. The food energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older. This factor compensated for a consistent bias in USDA-NFCS that was attributed to under-reporting of the foods consumed or the methods used to ascertain dietary intakes. Layton (1993) used a weighted average oxygen uptake of 0.05 L O_2/KJ which was determined from data reported in the 1977-78 USDA-NFCS and the second NHANES (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. A VQ of 27 used in the calculations was calculated as the geometric mean of VQ data that were obtained from several studies.

The inhalation rate estimation techniques are shown in footnote (a) of Table 6-36. Table 6-37 presents the daily inhalation rate for each age/gender cohort. The highest daily inhalation rates were 10 m^3/day for children between the ages of 6 and 8 years, 17 m^3/day for males between 15 and 18 years, and 13 m^3/day for females between 9 and 11 years. Inhalation rates were also calculated for active and inactive periods for the various age/gender cohorts.

The inhalation rate for inactive periods was estimated by multiplying the BMR times H times VQ. BMR was defined as "the minimum amount of energy required to support basic cellular respiration while at rest and not actively digesting food" (Layton, 1993). The inhalation rate for active periods was calculated by multiplying the inactive inhalation rate by the ratio of the rate of energy expenditure during active hours to the estimated BMR. This ratio is presented as F in Table 6-36. These data for active and inactive inhalation rates are also presented in Table 6-36. For children, inactive and active inhalation rates ranged from 2.35 to 5.95 m^3/day and from 6.35 to 13.09 m^3/day, respectively.

Second Approach

Inhalation rates were calculated as the product of the BMR of the population cohorts, the ratio of total daily energy expenditure to daily BMR, H, and VQ. The BMR data obtained from the literature were statistically analyzed, and regression equations were developed to predict BMR from body weights of various age/gender cohorts. The statistical data used to develop the regression equations are presented in Table 6-37. The data obtained from the second approach are presented in Table 6-38. Inhalation rates for children (6 months - 10 years) ranged from 7.3 to 9.3 m^3/day for male and 5.6 to 8.6 m^3/day for female children; for older children (10 to 18 years), inhalation rates were 15 m^3/day for males and 12 m^3/day for females. These rates are similar to the daily inhalation rates obtained using the first approach. Also, the inactive inhalation rates obtained from the first approach are lower than the inhalation rates obtained using the second approach. This may be attributed to the BMR multiplier employed in the equation of the second approach to calculate inhalation rates.

Inhalation rates were also obtained for short-term exposures for various age/gender cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of the metabolic equivalent, H, and VQ. The data obtained for short-term exposures are presented in Table 6-39.

This study obtained similar results using two different approaches. The major strengths of this study are that it estimates inhalation rates in different age groups and that the populations are large. Explanations for differences in results due to metabolic measurements, reported diet, or activity patterns are supported by observations reported by other investigators in other studies. Major limitations of this study are (1) the estimated activity pattern levels are somewhat subjective; (2) the explanation that activity pattern differences are responsible for the lower level obtained with the metabolic approach (25 %) compared to the activity pattern approach is not well supported by the data; and (3) different populations were used in each approach, which may have introduced error.

6.4.7 Rusconi et al., 1994 - Reference Values for Respiratory Rate in the First 3 Years of Life

Rusconi et al. (1994) examined a large number of infants and children in Milano, Italy in order to determine the reference values for respiratory rate in children aged 15 days to 3 years. A total of 618 infants and children (336 males and 282 females) who did not have respiratory infections or any severe disease were included in the study. Of the 618, a total of 309 were in good health and were observed in day care centers, while the remaining 309 were seen in hospitals or as outpatients.

Respiratory rates were recorded twice, 30 to 60 minutes apart, listening to breath sounds for 60 seconds with a stethoscope, when the child was awake and calm and when the child was sleeping quietly (sleep not associated with any spontaneous movement, including eye movements or vocalizations) (Table 6-40). The children were assessed for one year in order to determine the repeatability of the recordings, to compare respiratory rate counts obtained by stethoscope and by observation, and to construct reference percentile curves by age in a large number of subjects.

The authors plotted the differences between respiratory rate counts determined by stethoscope at 30- to 60-minute intervals against their mean count in waking and sleeping subjects. The standard deviation of the differences between the two counts was 2.5 and 1.7 breaths/minute, respectively, for waking and sleeping children. This standard deviation yielded 95% repeatability coefficients of 4.9 breaths/minute when the infants and children were awake and 3.3 breaths/minute when they were asleep.

In both waking and sleeping states, the respiratory rate counts determined by stethoscope were found to be higher than those obtained by observation. The mean difference was 2.6 and 1.8 breaths per minute, respectively, in waking and sleeping states. The mean respiratory rate counts were significantly higher in infants and children at all ages when awake and calm than when asleep. A decrease in respiratory rate with increasing age was seen in waking and sleeping infants and children. A scatter diagram of respiratory rate counts by age in waking and sleeping subjects showed that the pattern of respiratory rate decline with age was similar in both states, but it was much faster in the first few months of life. The authors constructed centile curves by first log-transforming the data and then applying a second degree polynormal curve, which allowed excellent fitting to observed data. Figures 6-1 and 6-2 show smoothed percentiles by age in waking and sleeping subjects, respectively. The variability of respiratory rate among subjects was higher in the first few months of life, which may be attributable to biological events that occur during these months, such as maturation of the neurologic control of breathing and changes in lung and chest wall compliance and lung volumes.

An advantage of this study is that it provides distribution data for respiratory rate for children from infancy (less than 2 months) to 36 months old. These data are not U.S. data; U.S. distributions were not available. Although, there is no reason to believe that the respiratory rates for Italian children would be different from that of U.S. children, this study only provided data for a narrow range of activities.

6.4.8 Price et al., 2003 - Modeling Interindividual Variation in Physiological Factors Used in PBPK Models of Humans

Price et al. (2003) developed a database of values for physiological parameters often used in physiologically-based pharmacokinetic models (PBPK). The database consisted of approximately 31,000 records containing information on volumes and masses of selected organs and tissues, blood flows for the organ and tissues, and total resting cardiac output and average inhalation rates. Records were created based on data from the NHANES III survey.

The study authors note that the database provides a source of data for human physiological parameters were the parameter values for an individual are correlated with one another and capture interindividual variation in populations of a specific gender, race, and age range. A computer program, Physiological Parameters for PBPK Modeling (PPPM or P^3M), which is publicly available (The Lifeline Group, 2007), was also developed to randomly retrieve records from the database for groups of individuals of specified age ranges, gender, and ethnicities. Price et al. (2003) recommends that output sets be used as inputs to Monte Carlo-based PBPK models of interindividual variation in dose.

6.5 REFERENCES FOR CHAPTER 6

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Table 6-4. Physiological Daily Inhalation Rates for Newborns Aged 1 Month or Less

Age Group	N	Body Weight (kg) Mean ± SD	Physiological Daily Inhalation Rates[e] Mean ± SD	
			(m^3/day)	(m^3/kg-day)
21 days (3 weeks)	13[a,c]	1.2 ± 0.2	0.85 ± 0.17[f]	0.74 ± 0.09[f]
32 days (~ 1 month)	10[b,d]	4.7 ± 0.7	2.45 ± 0.59[g]	0.53 ± 0.10[g]
33 days (~ 1 month)	10[a,d]	4.8 ± 0.3	2.99 ± 0.47[g]	0.62 ±0.09[g]

[a] Formula-fed infants.
[b] Breast-fed infants.
[c] Healthy infants with very low birth weight.
[d] Infants evaluated as being clinically healthy and neither underweight or overweight.
[e] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG)*H*(V_E/VO_2)*10^{-3}$, where H = 0.21 L of O_2/Kcal, $V_E/VO_2 = 27$ (Layton, 1993), TDEE = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).
[f] TDEEs based on nutritional balance measurements during 3-day periods.
[g] TDEEs based on ^2H_2O and $H_2{}^{18}O$ disappearance rates from urine

N = Number of individuals.
SD = Standard deviation.

Source: Brochu et al., 2006.

Table 6-5. Distribution Percentiles of Physiological Daily Inhalation Rates (m^3/day) for Free-living Normal-weight Males and Females Aged 2.6 months to 23 years

Age Group (years)	N	Body Weight[a] (kg) Mean ± SD	Physiological Daily Inhalation Rates[b] (m^3/day)								
			Mean ± SD	Percentile[c]							
				5th	10th	25th	50th	75th	90th	95th	99th
Males											
0.22 to <0.5	32	6.7 ± 1.0	3.38 ± 0.72	2.19	2.46	2.89	3.38	3.87	4.30	4.57	5.06
0.5 to <1	40	8.8 ± 1.1	4.22 ± 0.79	2.92	3.21	3.69	4.22	4.75	5.23	5.51	6.05
1 to <2	35	10.6 ± 1.1	5.12 ± 0.88	3.68	3.99	4.53	5.12	5.71	6.25	6.56	7.16
2 to <5	25	15.3 ± 3.4	7.60 ± 1.28	5.49	5.95	6.73	7.60	8.47	9.25	9.71	10.59
5 to <7	96	19.8 ± 2.1	8.64 ± 1.23	6.61	7.06	7.81	8.64	9.47	10.21	10.66	11.50
7 to <11	38	28.9 ± 5.6	10.59 ± 1.99	7.32	8.04	9.25	10.59	11.94	13.14	13.87	15.22
11 to <23	30	58.6 ± 13.9	17.23 ± 3.67	11.19	12.53	14.75	17.23	19.70	21.93	23.26	25.76
Females											
0.22 to <0.5	53	6.5 ± 0.9	3.26 ± 0.66	2.17	2.41	2.81	3.26	3.71	4.11	4.36	4.81
0.5 to <1	63	8.5 ± 1.0	3.96 ± 0.72	2.78	3.05	3.48	3.96	4.45	4.88	5.14	5.63
1 to <2	66	10.6 ± 1.3	4.78 ± 0.96	3.20	3.55	4.13	4.78	5.43	6.01	6.36	7.02
2 to <5	36	14.4 ± 3.0	7.06 ± 1.16	5.15	5.57	6.28	7.06	7.84	8.54	8.97	9.76
5 to <7	102	19.7 ± 2.3	8.22 ± 1.31	6.06	6.54	7.34	8.22	9.11	9.90	10.38	11.27
7 to <11	161	28.3 ± 4.4	9.84 ± 1.69	7.07	7.68	8.70	9.84	10.98	12.00	12.61	13.76
11 to <23	87	50.0 ± 8.9	13.28 ± 2.60	9.00	9.94	11.52	13.28	15.03	16.61	17.56	19.33

[a] Measured body weight. Normal-weight individuals defined according to the body mass index (BMI) cut-offs.
[b] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG)*H*(V_E/VO_2)*10^{-3}$, where H = 0.21 L of O_2/Kcal, $V_E/VO_2 = 27$ (Layton, 1993), TDEE = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).
[c] Percentiles based on a normal distribution assumption for age groups.
N = Number of individuals.
SD = Standard deviation.

Source: Brochu et al., 2006.

Table 6-6. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Free-living Normal-weight Males, Females, and Males and Females Combined.

Age Group[a]	N	Mean	95th
Males			
3 to <6 months[b]	32	3.38	4.57
6 to <12 months	40	4.42	5.51
1 to <2 years	35	5.12	6.56
Females			
3 to <6 months[b]	53	3.26	4.36
6 to <12 months	63	3.96	5.14
1 to <2 years	66	4.78	6.36
Males and Females Combined			
3 to <6 months[b]	85	3.32	4.47
6 to <12 months	103	4.09	5.53
1 to <2 years	101	4.95	6.46

[a] No other age groups from Table 6-5 (Brochu et al., 2006) fit into the U.S. EPA age groupings.
[b] Age group from Brochu et al. (2006) was 2.6 to <6 months.
N = Number of individuals.

Source: Brochu et al., 2006.

Table 6-7. Distribution Percentiles of Physiological Daily Inhalation Rates (m^3/day) for Free-living Normal-weight and Overweight/obese Males and Females Aged 4 to 18 years

Age Group (years)	N	Body Weight[a] (kg) Mean ± SD	Physiological Daily Inhalation Rates[b] (m^3/day) Mean ± SD	Percentile[c] 5th	10th	25th	50th	75th	90th	95th	99th
Males - Normal-weight											
4 to <5.1	77	19.0 ± 1.9	7.90 ± 0.97	6.31	6.66	7.25	7.90	8.56	9.15	9.50	10.16
5.1 to <9.1	52	22.6 ± 3.5	9.14 ± 1.44	6.77	7.29	8.17	9.14	10.11	10.99	11.51	12.49
9.1 to <18.1	36	41.4 ± 12.1	13.69 ± 3.95	7.19	8.63	11.02	13.69	16.35	18.75	20.19	22.88
Males - Overweight/obese											
4 to <5.1	54	26.5 ± 4.9	9.59 ± 1.26	7.52	7.98	8.74	9.59	10.44	11.21	11.66	12.52
5.1 to <9.1	40	32.5 ± 9.2	10.88 ± 2.49	6.78	7.69	9.20	10.88	12.56	14.07	14.98	16.68
9.1 to <18.1	33	55.8 ± 10.8	14.52 ± 1.98	11.25	11.98	13.18	14.52	15.85	17.06	17.78	19.13
Females - Normal-weight											
4 to <5.1	82	18.7 ± 2.0	7.41 ± 0.91	5.92	6.25	6.80	7.41	8.02	8.57	8.90	9.52
5.1 to <9.1	151	25.5 ± 4.1	9.39 ± 1.62	6.72	7.31	8.30	9.39	10.48	11.47	12.05	13.16
9.1 to <18.1	124	42.7 ± 11.1	12.04 ± 2.86	7.34	8.38	10.11	12.04	13.97	15.70	16.74	18.68
Females - Overweight/obese											
4 to <5.1	56	26.1 ± 5.5	8.70 ± 1.13	6.84	7.26	7.94	8.70	9.47	10.15	10.56	11.33
5.1 to <9.1	68	34.6 ± 9.9	10.55 ± 2.23	6.88	7.69	9.05	10.55	12.06	13.41	14.22	15.75
9.1 to <18.1	68	59.2 ± 12.8	14.27 ± 2.70	9.83	10.81	12.45	14.27	16.09	17.73	18.71	20.55

[a] Measured body weight. Normal-weight and overweight/obese males defined according to the body mass index (BMI) cut-offs.

[b] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG)*H*(V_E/VO_2)*10^{-3}$, where H = 0.21 L of O_2/Kcal, $V_E/VO_2 = 27$ (Layton, 1993), TDEE = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).

[c] Percentiles based on a normal distribution assumption for age groups.

N = Number of individuals.

SD = Standard deviation.

Source: Brochu et al., 2006.

Table 6-8. Distribution Percentiles of Physiological Daily Inhalation Rates per Unit of Body Weight (m^3/kg-day) for Free-living Normal-weight Males and Females Aged 2.6 months to 23 years

Age Group (years)	Physiological Daily Inhalation Rates[a] (m^3/kg-day)								
	Mean ± SD	Percentile[b]							
		5th	10th	25th	50th	75th	90th	95th	99th
Males									
0.22 to <0.5	0.51 ± 0.09	0.36	0.39	0.45	0.51	0.57	0.63	0.66	0.73
0.5 to <1	0.48 ± 0.07	0.36	0.39	0.43	0.48	0.53	0.57	0.60	0.64
1 to <2	0.48 ± 0.06	0.38	0.41	0.44	0.48	0.52	0.56	0.58	0.62
2 to <5	0.44 ± 0.04	0.38	0.39	0.42	0.44	0.47	0.50	0.51	0.54
5 to <7	0.42 ± 0.05	0.34	0.35	0.38	0.42	0.45	0.48	0.49	0.52
7 to <11	0.37 ± 0.06	0.27	0.29	0.33	0.37	0.41	0.45	0.47	0.52
11 to <23	0.30 ± 0.05	0.22	0.24	0.27	0.30	0.33	0.36	0.38	0.41
Females									
0.22 to <0.5	0.50 ± 0.09	0.35	0.39	0.44	0.50	0.57	0.62	0.66	0.72
0.5 to <1	0.46 ± 0.06	0.36	0.38	0.42	0.46	0.51	0.55	0.57	0.61
1 to <2	0.45 ± 0.08	0.33	0.35	0.40	0.45	0.50	0.55	0.58	0.63
2 to <5	0.44 ± 0.07	0.32	0.35	0.39	0.44	0.49	0.53	0.56	0.61
5 to <7	0.40 ± 0.05	0.32	0.33	0.36	0.40	0.43	0.46	0.47	0.51
7 to <11	0.35 ± 0.06	0.25	0.27	0.31	0.35	0.39	0.43	0.45	0.50
11 to <23	0.27 ± 0.05	0.19	0.21	0.24	0.27	0.30	0.33	0.35	0.38

[a] Physiological daily inhalation rates were calculated using the following equation: (TDEE + ECG)*H*(V_E/VO_2)*10^{-3}, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993), TDEE = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).

[b] Percentiles based on a normal distribution assumption for age groups.

SD = Standard deviation.

Source: Brochu et al., 2006.

Table 6-9. Distribution Percentiles of Physiological Daily Inhalation Rates (m^3/kg-day) for Free-living Normal-weight and Overweight/obese Males and Females Aged 4 to 18 years

Age Group (years)	Physiological Daily Inhalation Rates[a] (m^3/kg-day)								
	Mean ± SD	Percentile[b]							
		5th	10th	25th	50th	75th	90th	95th	99th
Males - Normal-weight									
4 to <5.1	0.42 ± 0.04	0.35	0.36	0.39	0.42	0.45	0.47	0.49	0.52
5.1 to <9.1	0.41 ± 0.06	0.31	0.34	0.37	0.41	0.45	0.48	0.50	0.54
9.1 to <18.1	0.33 ± 0.05	0.26	0.27	0.30	0.33	0.37	0.40	0.41	0.45
Males - Overweight/obese									
4 to <5.1	0.37 ± 0.04	0.30	0.31	0.34	0.37	0.40	0.42	0.44	0.47
5.1 to <9.1	0.35 ± 0.08	0.22	0.25	0.29	0.35	0.40	0.45	0.47	0.53
9.1 to <18.1	0.27 ± 0.04	0.20	0.22	0.24	0.27	0.29	0.32	0.33	0.36
Females - Normal-weight									
4 to <5.1	0.40 ± 0.05	0.32	0.34	0.37	0.40	0.43	0.46	0.48	0.51
5.1 to <9.1	0.37 ± 0.06	0.27	0.29	0.33	0.37	0.41	0.45	0.47	0.52
9.1 to <18.1	0.29 ± 0.06	0.20	0.22	0.25	0.29	0.33	0.36	0.38	0.42
Females - Overweight/obese									
4 to <5.1	0.34 ± 0.04	0.27	0.28	0.31	0.34	0.37	0.40	0.41	0.44
5.1 to <9.1	0.32 ± 0.07	0.21	0.23	0.27	0.32	0.36	0.40	0.43	0.47
9.1 to <18.1	0.25 ± 0.05	0.17	0.18	0.21	0.25	0.28	0.31	0.33	0.36

[a] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG)*H*(V_E/VO_2)*10^{-3}$, where H = 0.21 L of O_2/Kcal, $V_E/VO_2 = 27$ (Layton, 1993), TDEE = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).

[b] Percentiles based on a normal distribution assumption for age groups.

SD = Standard deviation.

Source: Brochu et al., 2006.

Table 6-10. Descriptive Statistics for Daily Average Inhalation Rate in Males, by Age Category[a]

Age Group	N	Daily Average Inhalation Rate, Unadjusted for Body Weight (m^3/day)								
		Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	419	8.76	4.77	5.70	7.16	8.70	10.43	11.93	12.69	17.05
1 to < 2 years	308	13.49	9.73	10.41	11.65	13.11	15.02	17.03	17.89	24.24
2 to < 3 years	261	13.23	9.45	10.20	11.43	13.19	14.49	16.27	17.71	28.17
3 to <6 years	540	12.65	10.42	10.87	11.40	12.58	13.64	14.63	15.41	19.52
6 to <11 years	940	13.42	10.08	10.69	11.73	13.09	14.73	16.56	17.72	24.97
11 to <16 years	1337	15.32	11.41	12.11	13.27	14.79	16.81	19.54	21.21	28.54
16 to <21 years	1241	17.22	12.60	13.41	14.48	16.63	19.16	21.94	23.38	39.21
Age Group	N	Daily Average Inhalation Rate, Adjusted for Body Weight (m^3/day-kg)								
		Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	419	1.09	0.91	0.94	1.00	1.09	1.16	1.26	1.29	1.48
1 to < 2 years	308	1.19	0.96	1.02	1.09	1.17	1.26	1.37	1.48	1.73
2 to < 3 years	261	0.95	0.78	0.82	0.87	0.94	1.01	1.09	1.13	1.36
3 to <6 years	540	0.70	0.52	0.56	0.61	0.69	0.78	0.87	0.92	1.08
6 to <11 years	940	0.44	0.32	0.34	0.38	0.43	0.50	0.55	0.58	0.81
11 to <16 years	1337	0.29	0.21	0.22	0.25	0.28	0.32	0.36	0.38	0.51
16 to <21 years	1241	0.23	0.17	0.18	0.20	0.23	0.25	0.28	0.30	0.40

[a] Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Inhalation rate was estimated using a multiple linear regression model.
N = Number of individuals.
BW = Body weight.

Source: U.S. EPA, 2006.

Table 6-11. Descriptive Statistics for Daily Average Inhalation Rate in Females, by Age Category[a]

Age Group	N	Daily Average Inhalation Rate, Unadjusted for Body Weight (m^3/day) Mean	Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Birth to <1 year	415	8.53	4.84	5.48	6.83	8.41	9.78	11.65	12.66	26.26
1 year	245	13.31	9.08	10.12	11.24	13.03	14.64	17.45	18.62	24.77
2 years	255	12.74	8.91	10.07	11.38	12.60	13.96	15.58	16.37	23.01
3 to <6 years	543	12.16	9.87	10.38	11.20	12.02	13.01	14.03	14.93	19.74
6 to <11 years	894	12.41	9.99	10.35	11.01	11.95	13.42	15.13	16.34	20.82
11 to <16 years	1,451	13.44	10.47	11.11	12.04	13.08	14.54	16.25	17.41	26.58
16 to <21 years	1,182	13.59	9.86	10.61	11.78	13.20	15.02	17.12	18.29	30.11
Age Group	**N**	**Daily Average Inhalation Rate, Adjusted for Body Weight (m^3/day-kg) Mean**	**Percentiles 5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**Maximum**
Birth to <1 year	415	1.14	0.91	0.97	1.04	1.13	1.24	1.33	1.38	1.60
1 year	245	1.20	0.98	1.01	1.10	1.18	1.30	1.41	1.47	1.73
2 years	255	0.96	0.82	0.84	0.89	0.96	1.01	1.07	1.11	1.23
3 to <6 years	543	0.69	0.48	0.54	0.60	0.68	0.77	0.88	0.92	1.12
6 to <11 years	894	0.43	0.28	0.31	0.36	0.43	0.49	0.55	0.58	0.75
11 to <16 years	1,451	0.25	0.19	0.20	0.22	0.25	0.28	0.31	0.34	0.47
16 to <21 years	1,182	0.21	0.16	0.17	0.19	0.21	0.24	0.27	0.28	0.36

[a] Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Inhalation rate was estimated using a multiple linear regression model.

N = Number of individuals.

Source: U.S. EPA, 2006.

Table 6-12. Mean and 95[th] Percentile Inhalation Rate Values (m^3/day) for Males, Females and Males and Females Combined

Age Group[a]	N	Mean	95[th]
Males			
Birth to <1 year	419	8.76	12.69
1 to <2 years	308	13.49	17.89
2 to <3 years	261	13.23	17.71
3 to <6 years	540	12.65	15.41
6 to <11 years	940	16.42	17.72
11 to <16 years	1,337	15.32	21.21
16 to <21 years	1,241	17.22	23.38
Females			
Birth to <1 year	415	8.53	12.66
1 to <2 years	245	13.31	18.62
2 to <3 years	255	12.74	16.37
3 to <6 years	543	12.16	14.93
6 to <11 years	894	12.41	16.34
11 to <16 years	1,451	13.44	17.41
16 to <21 years	1,182	13.59	18.29
Males and Females Combined			
Birth to <1 year	834	8.65	12.68
1 to <2 years	553	13.40	18.26
2 to <3 years	516	12.99	17.04
3 to <6 years	1,083	12.41	15.17
6 to <11 years	1,834	12.92	17.03
11 to <16 years	2,788	14.38	19.31
16 to <21 years	2423	15.41	20.84

[a] No other age groups from Tables 6-9 and 6-10 (U.S. EPA, 2006) fit into the EPA age groupings.
N = Number of individuals.

Source: U.S. EPA, 2006.

Table 6-13. Descriptive Statistics for Average Ventilation Rate[a] While Performing Activities Within the Specified Activity Category, for Males by Age Category

Age Group	N	Average Ventilation Rate (m^3/min), Unadjusted for Body Weight									Average Ventilation Rate (m^3/min-kg), Adjusted for Body Weight								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Sleep or nap (Activity ID = 14500)																			
Birth to <1 year	419	3.08E-03	1.66E-03	1.91E-03	2.45E-03	3.00E-03	3.68E-03	4.35E-03	4.77E-03	7.19E-03	3.85E-04	2.81E-04	3.01E-04	3.37E-04	3.80E-04	4.27E-04	4.65E-04	5.03E-04	6.66E-04
1 year	308	4.50E-03	3.11E-03	3.27E-03	3.78E-03	4.35E-03	4.95E-03	5.90E-03	6.44E-03	1.00E-02	3.95E-04	2.95E-04	3.13E-04	3.45E-04	3.84E-04	4.41E-04	4.91E-04	5.24E-04	6.26E-04
2 years	261	4.61E-03	3.01E-03	3.36E-03	3.94E-03	4.49E-03	5.21E-03	6.05E-03	6.73E-03	8.96E-03	3.30E-04	2.48E-04	2.60E-04	2.89E-04	3.26E-04	3.62E-04	4.05E-04	4.42E-04	5.38E-04
3 to <6 years	540	4.36E-03	3.06E-03	3.30E-03	3.76E-03	4.29E-03	4.86E-03	5.54E-03	5.92E-03	7.67E-03	2.43E-04	1.60E-04	1.74E-04	1.98E-04	2.37E-04	2.79E-04	3.14E-04	3.50E-04	4.84E-04
6 to <11 years	940	4.61E-03	3.14E-03	3.39E-03	3.83E-03	4.46E-03	5.21E-03	6.01E-03	6.54E-03	9.94E-03	1.51E-04	1.02E-04	1.09E-04	1.25E-04	1.48E-04	1.74E-04	2.00E-04	2.15E-04	3.02E-04
11 to <16 years	1,337	5.26E-03	3.53E-03	3.78E-03	4.34E-03	5.06E-03	5.91E-03	6.94E-03	7.81E-03	1.15E-02	9.80E-05	6.70E-05	7.20E-05	8.10E-05	9.40E-05	1.10E-04	1.29E-04	1.41E-04	2.08E-04
16 to <21 years	1,241	5.31E-03	3.55E-03	3.85E-03	4.35E-03	5.15E-03	6.09E-03	6.92E-03	7.60E-03	1.28E-02	7.10E-05	4.70E-05	5.20E-05	6.10E-05	6.90E-05	8.00E-05	9.00E-05	9.80E-05	1.47E-04
Sedentary & Passive Activities (METS ≤ 1.5 -- Includes Sleep or Nap)																			
Birth to <1 year	419	3.18E-03	1.74E-03	1.99E-03	2.50E-03	3.10E-03	3.80E-03	4.40E-03	4.88E-03	7.09E-03	3.97E-04	3.03E-04	3.17E-04	3.51E-04	3.91E-04	4.37E-04	4.70E-04	4.98E-04	6.57E-04
1 year	308	4.62E-03	3.17E-03	3.50E-03	3.91E-03	4.49E-03	5.03E-03	5.95E-03	6.44E-03	9.91E-03	4.06E-04	3.21E-04	3.31E-04	3.63E-04	3.97E-04	4.48E-04	4.88E-04	5.25E-04	6.19E-04
2 years	261	4.79E-03	3.25E-03	3.66E-03	4.10E-03	4.69E-03	5.35E-03	6.05E-03	6.71E-03	9.09E-03	3.43E-04	2.74E-04	2.86E-04	3.09E-04	3.40E-04	3.69E-04	4.05E-04	4.46E-04	5.10E-04
3 to <6 years	540	4.58E-03	3.47E-03	3.63E-03	4.07E-03	4.56E-03	5.03E-03	5.58E-03	5.82E-03	7.60E-03	2.55E-04	1.78E-04	1.93E-04	2.15E-04	2.50E-04	2.88E-04	3.27E-04	3.46E-04	4.54E-04
6 to <11 years	940	4.87E-03	3.55E-03	3.78E-03	4.18E-03	4.72E-03	5.40E-03	6.03E-03	6.58E-03	9.47E-03	1.60E-04	1.13E-04	1.18E-04	1.35E-04	1.57E-04	1.80E-04	2.09E-04	2.18E-04	2.89E-04
11 to <16 years	1,337	5.64E-03	4.03E-03	4.30E-03	4.79E-03	5.43E-03	6.26E-03	7.20E-03	7.87E-03	1.11E-02	1.05E-04	7.70E-05	8.00E-05	8.80E-05	1.01E-04	1.18E-04	1.35E-04	1.42E-04	1.95E-04
16 to <21 years	1,241	5.76E-03	4.17E-03	4.42E-03	4.93E-03	5.60E-03	6.43E-03	7.15E-03	7.76E-03	1.35E-02	7.70E-05	5.50E-05	6.00E-05	6.80E-05	7.60E-05	8.50E-05	9.50E-05	1.02E-04	1.32E-04
Light Intensity Activities (1.5 < METS ≤ 3.0)																			
Birth to <1 year	419	7.94E-03	4.15E-03	5.06E-03	6.16E-03	7.95E-03	9.57E-03	1.08E-02	1.19E-02	1.55E-02	9.88E-04	7.86E-04	8.30E-04	8.97E-04	9.72E-04	1.07E-03	1.17E-03	1.20E-03	1.44E-03
1 year	308	1.16E-02	8.66E-03	8.99E-03	9.89E-03	1.14E-02	1.29E-02	1.44E-02	1.58E-02	2.11E-02	1.02E-03	8.36E-04	8.59E-04	9.18E-04	1.01E-03	1.10E-03	1.22E-03	1.30E-03	1.49E-03
2 years	261	1.17E-02	8.52E-03	9.14E-03	9.96E-03	1.14E-02	1.30E-02	1.47E-02	1.53E-02	1.90E-02	8.37E-04	6.83E-04	7.16E-04	7.61E-04	8.26E-04	8.87E-04	9.95E-04	1.03E-03	1.18E-03
3 to <6 years	540	1.14E-02	9.20E-03	9.55E-03	1.02E-02	1.11E-02	1.23E-02	1.34E-02	1.40E-02	1.97E-02	6.33E-04	4.41E-04	4.80E-04	5.44E-04	6.26E-04	7.11E-04	7.94E-04	8.71E-04	1.08E-03
6 to <11 years	940	1.16E-02	8.95E-03	9.33E-03	1.02E-02	1.13E-02	1.28E-02	1.46E-02	1.56E-02	2.18E-02	3.84E-04	2.67E-04	2.86E-04	3.24E-04	3.77E-04	4.37E-04	4.93E-04	5.29E-04	7.09E-04
11 to <16 years	1,337	1.32E-02	9.78E-03	1.03E-02	1.13E-02	1.28E-02	1.47E-02	1.64E-02	1.87E-02	2.69E-02	2.46E-04	1.76E-04	1.87E-04	2.09E-04	2.38E-04	2.82E-04	3.11E-04	3.32E-04	4.42E-04
16 to <21 years	1,241	1.34E-02	1.00E-02	1.05E-02	1.15E-02	1.30E-02	1.50E-02	1.70E-02	1.80E-02	2.91E-02	1.79E-04	1.37E-04	1.44E-04	1.56E-04	1.78E-04	1.99E-04	2.18E-04	2.30E-04	3.32E-04

Table 6-13. Descriptive Statistics for Average Ventilation Rate[a] While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group	N	Average Ventilation Rate (m^3/min), Unadjusted for Body Weight									Average Ventilation Rate (m^3/min-kg), Adjusted for Body Weight								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Moderate Intensity Activities (3.0 < METS ≤ 6.0)																			
Birth to <1 year	419	1.45E-02	7.41E-03	8.81E-03	1.15E-02	1.44E-02	1.70E-02	2.01E-02	2.25E-02	3.05E-02	1.80E-03	1.40E-03	1.49E-03	1.62E-03	1.78E-03	1.94E-03	2.18E-03	2.28E-03	3.01E-03
1 year	308	2.14E-02	1.45E-02	1.59E-02	1.80E-02	2.06E-02	2.41E-02	2.69E-02	2.89E-02	3.99E-02	1.88E-03	1.41E-03	1.50E-03	1.65E-03	1.82E-03	2.02E-03	2.34E-03	2.53E-03	3.23E-03
2 years	261	2.15E-02	1.54E-02	1.67E-02	1.84E-02	2.08E-02	2.41E-02	2.69E-02	2.97E-02	5.09E-02	1.55E-03	1.21E-03	1.28E-03	1.40E-03	1.54E-03	1.66E-03	1.84E-03	2.02E-03	2.29E-03
3 to <6 years	540	2.10E-02	1.63E-02	1.72E-02	1.87E-02	2.06E-02	2.29E-02	2.56E-02	2.71E-02	3.49E-02	1.17E-03	8.05E-04	8.83E-04	9.99E-04	1.12E-03	1.31E-03	1.56E-03	1.68E-03	2.10E-03
6 to <11 years	940	2.23E-02	1.64E-02	1.72E-02	1.93E-02	2.16E-02	2.50E-02	2.76E-02	2.95E-02	4.34E-02	7.36E-04	5.03E-04	5.45E-04	6.18E-04	7.14E-04	8.34E-04	9.58E-04	1.04E-03	1.43E-03
11 to <16 years	1,337	2.64E-02	1.93E-02	2.05E-02	2.26E-02	2.54E-02	2.92E-02	3.38E-02	3.69E-02	5.50E-02	4.91E-04	3.59E-04	3.75E-04	4.18E-04	4.73E-04	5.52E-04	6.35E-04	6.81E-04	1.06E-03
16 to <21 years	1,241	2.90E-02	2.03E-02	2.17E-02	2.45E-02	2.80E-02	3.17E-02	3.82E-02	4.21E-02	6.74E-02	3.87E-04	2.81E-04	2.96E-04	3.34E-04	3.80E-04	4.31E-04	4.86E-04	5.18E-04	7.11E-04
High Intensity (METS > 6.0)																			
Birth to <1 year	183	2.75E-02	1.51E-02	1.73E-02	2.06E-02	2.78E-02	3.25E-02	3.84E-02	4.22E-02	5.79E-02	3.48E-03	2.70E-03	2.93E-03	3.10E-03	3.46E-03	3.81E-03	4.14E-03	4.32E-03	5.08E-03
1 year	164	4.03E-02	2.83E-02	3.17E-02	3.47E-02	3.98E-02	4.43E-02	5.16E-02	5.59E-02	6.07E-02	3.52E-03	2.52E-03	2.89E-03	3.22E-03	3.57E-03	3.91E-03	4.11E-03	4.34E-03	4.86E-03
2 years	162	4.05E-02	2.82E-02	2.97E-02	3.45E-02	4.06E-02	4.62E-02	5.19E-02	5.51E-02	9.20E-02	2.89E-03	2.17E-03	2.34E-03	2.58E-03	2.87E-03	3.20E-03	3.43E-03	3.54E-03	4.30E-03
3 to <6 years	263	3.90E-02	2.95E-02	3.14E-02	3.40E-02	3.78E-02	4.32E-02	4.89E-02	5.22E-02	6.62E-02	2.17E-03	1.55E-03	1.66E-03	1.81E-03	2.11E-03	2.50E-03	2.73E-03	2.98E-03	3.62E-03
6 to <11 years	637	4.36E-02	3.07E-02	3.28E-02	3.58E-02	4.19E-02	4.95E-02	5.66E-02	6.24E-02	8.99E-02	1.41E-03	9.36E-04	1.03E-03	1.19E-03	1.38E-03	1.59E-03	1.83E-03	1.93E-03	2.68E-03
11 to <16 years	1,111	5.08E-02	3.43E-02	3.68E-02	4.15E-02	4.91E-02	5.74E-02	6.63E-02	7.29E-02	1.23E-01	9.50E-04	6.35E-04	6.96E-04	7.90E-04	9.09E-04	1.09E-03	1.27E-03	1.36E-03	1.98E-03
16 to <21 years	968	5.32E-02	3.60E-02	3.83E-02	4.35E-02	5.05E-02	5.93E-02	7.15E-02	8.30E-02	1.30E-01	7.11E-04	4.75E-04	5.27E-04	5.99E-04	6.91E-04	8.02E-04	9.17E-04	9.97E-04	1.94E-03

a An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

N = Number of individuals.

MET = Metabolic equivalent.

Source: U.S. EPA, 2006.

Table 6-14. Descriptive Statistics for Average Ventilation Rate[a] While Performing Activities Within the Specified Activity Category, for Females by Age Category

Age Group	N	Average Ventilation Rate (m^3/min), Unadjusted for Body Weight									Average Ventilation Rate (m^3/min-kg), Adjusted for Body Weight								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Sleep or nap (Activity ID = 14500)																			
Birth to <1 year	415	2.92E-03	1.54E-03	1.72E-03	2.27E-03	2.88E-03	3.50E-03	4.04E-03	4.40E-03	8.69E-03	3.91E-04	2.80E-04	3.01E-04	3.35E-04	3.86E-04	4.34E-04	4.79E-04	5.17E-04	7.39E-04
1 year	245	4.59E-03	3.02E-03	3.28E-03	3.76E-03	4.56E-03	5.32E-03	5.96E-03	6.37E-03	9.59E-03	4.14E-04	3.15E-04	3.29E-04	3.61E-04	4.05E-04	4.64E-04	5.21E-04	5.36E-04	6.61E-04
2 years	255	4.56E-03	3.00E-03	3.30E-03	3.97E-03	4.52E-03	5.21E-03	5.76E-03	6.15E-03	9.48E-03	3.42E-04	2.58E-04	2.71E-04	2.93E-04	3.33E-04	3.91E-04	4.25E-04	4.53E-04	4.94E-04
3 to <6 years	543	4.18E-03	2.90E-03	3.20E-03	3.62E-03	4.10E-03	4.71E-03	5.22E-03	5.73E-03	7.38E-03	2.38E-04	1.45E-04	1.63E-04	1.95E-04	2.33E-04	2.75E-04	3.20E-04	3.53E-04	5.19E-04
6 to <11 years	894	4.36E-03	2.97E-03	3.17E-03	3.69E-03	4.24E-03	4.93E-03	5.67E-03	6.08E-03	8.42E-03	1.51E-04	8.90E-05	9.70E-05	1.20E-04	1.46E-04	1.76E-04	2.11E-04	2.29E-04	2.97E-04
11 to <16 years	1,451	4.81E-03	3.34E-03	3.57E-03	3.99E-03	4.66E-03	5.39E-03	6.39E-03	6.99E-03	9.39E-03	9.00E-05	5.90E-05	6.50E-05	7.50E-05	8.70E-05	1.02E-04	1.18E-04	1.30E-04	1.76E-04
16 to <21 years	1,182	4.40E-03	2.78E-03	2.96E-03	3.58E-03	4.26E-03	5.05E-03	5.89E-03	6.63E-03	1.23E-02	6.90E-05	4.40E-05	4.70E-05	5.70E-05	6.70E-05	8.00E-05	9.30E-05	1.02E-04	1.52E-04
Sedentary & Passive Activities (METS ≤ 1.5 -- Includes Sleep or Nap)																			
Birth to <1 year	415	3.00E-03	1.60E-03	1.80E-03	2.32E-03	2.97E-03	3.58E-03	4.11E-03	4.44E-03	9.59E-03	4.02E-04	2.97E-04	3.16E-04	3.52E-04	3.96E-04	4.46E-04	4.82E-04	5.19E-04	7.19E-04
1 year	245	4.71E-03	3.26E-03	3.44E-03	3.98E-03	4.73E-03	5.30E-03	5.95E-03	6.63E-03	9.50E-03	4.25E-04	3.35E-04	3.48E-04	3.76E-04	4.18E-04	4.69E-04	5.12E-04	5.43E-04	6.42E-04
2 years	255	4.73E-03	3.34E-03	3.53E-03	4.19E-03	4.67E-03	5.25E-03	5.75E-03	6.22E-03	9.42E-03	3.55E-04	2.85E-04	2.96E-04	3.20E-04	3.48E-04	3.91E-04	4.20E-04	4.42E-04	4.85E-04
3 to <6 years	543	4.40E-03	3.31E-03	3.49E-03	3.95E-03	4.34E-03	4.84E-03	5.29E-03	5.73E-03	7.08E-03	2.51E-04	1.64E-04	1.79E-04	2.11E-04	2.48E-04	2.84E-04	3.28E-04	3.58E-04	4.89E-04
6 to <11 years	894	4.64E-03	3.41E-03	3.67E-03	4.04E-03	4.51E-03	5.06E-03	5.88E-03	6.28E-03	8.31E-03	1.60E-04	9.90E-05	1.10E-04	1.31E-04	1.57E-04	1.85E-04	2.12E-04	2.34E-04	2.93E-04
11 to <16 years	1,451	5.21E-03	3.90E-03	4.16E-03	4.53E-03	5.09E-03	5.68E-03	6.53E-03	7.06E-03	9.07E-03	9.70E-05	7.10E-05	7.50E-05	8.30E-05	9.50E-05	1.09E-04	1.23E-04	1.33E-04	1.74E-04
16 to <21 years	1,182	4.76E-03	3.26E-03	3.56E-03	4.03E-03	4.69E-03	5.32E-03	6.05E-03	6.60E-03	1.18E-02	7.50E-05	5.30E-05	5.70E-05	6.30E-05	7.40E-05	8.50E-05	9.60E-05	1.04E-04	1.41E-04
Light Intensity Activities (1.5 < METS ≤ 3.0)																			
Birth to <1 year	415	7.32E-03	3.79E-03	4.63E-03	5.73E-03	7.19E-03	8.73E-03	9.82E-03	1.08E-02	1.70E-02	9.78E-04	7.91E-04	8.17E-04	8.80E-04	9.62E-04	1.05E-03	1.18E-03	1.23E-03	1.65E-03
1 year	245	1.16E-02	8.59E-03	8.80E-03	1.00E-02	1.12E-02	1.29E-02	1.52E-02	1.58E-02	2.02E-02	1.05E-03	8.45E-04	8.68E-04	9.49E-04	1.04E-03	1.14E-03	1.25E-03	1.27E-03	1.64E-03
2 years	255	1.20E-02	8.74E-03	9.40E-03	1.03E-02	1.17E-02	1.32E-02	1.56E-02	1.63E-02	2.36E-02	8.97E-04	7.30E-04	7.63E-04	8.19E-04	8.93E-04	9.64E-04	1.04E-03	1.10E-03	1.26E-03
3 to <6 years	543	1.09E-02	8.83E-03	9.04E-03	9.87E-03	1.07E-02	1.17E-02	1.29E-02	1.38E-02	1.64E-02	6.19E-04	4.48E-04	4.84E-04	5.37E-04	5.99E-04	6.98E-04	7.83E-04	8.28E-04	1.02E-03
6 to <11 years	894	1.11E-02	8.51E-03	9.02E-03	9.79E-03	1.08E-02	1.20E-02	1.35E-02	1.47E-02	2.22E-02	3.82E-04	2.52E-04	2.70E-04	3.15E-04	3.76E-04	4.42E-04	5.03E-04	5.39E-04	7.10E-04
11 to <16 years	1,451	1.20E-02	9.40E-03	9.73E-03	1.06E-02	1.18E-02	1.31E-02	1.47E-02	1.58E-02	2.21E-02	2.25E-04	1.63E-04	1.74E-04	1.96E-04	2.17E-04	2.49E-04	2.84E-04	3.05E-04	3.96E-04
16 to <21 years	1,182	1.11E-02	8.31E-03	8.73E-03	9.64E-03	1.08E-02	1.23E-02	1.38E-02	1.49E-02	2.14E-02	1.74E-04	1.29E-04	1.38E-04	1.54E-04	1.73E-04	1.93E-04	2.13E-04	2.24E-04	2.86E-04

Table 6-14. Descriptive Statistics for Average Ventilation Rate[a] While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

AgeGroup	N	Average Ventilation Rate (m^3/min), Unadjusted for Body Weight									Average Ventilation Rate (m^3/min-kg), Adjusted for Body Weight								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Moderate Intensity Activities (3.0 < METS ≤ 6.0)																			
Birth to <1 year	415	1.40E-02	7.91E-03	9.00E-03	1.12E-02	1.35E-02	1.63E-02	1.94E-02	2.23E-02	4.09E-02	1.87E-03	1.47E-03	1.52E-03	1.67E-03	1.85E-03	2.01E-03	2.25E-03	2.40E-03	2.83E-03
1 year	245	2.10E-02	1.56E-02	1.63E-02	1.79E-02	2.01E-02	2.35E-02	2.71E-02	2.93E-02	3.45E-02	1.90E-03	1.52E-03	1.62E-03	1.73E-03	1.87E-03	2.02E-03	2.24E-03	2.37E-03	3.24E-03
2 years	255	2.13E-02	1.42E-02	1.56E-02	1.82E-02	2.15E-02	2.39E-02	2.76E-02	2.88E-02	3.76E-02	1.60E-03	1.27E-03	1.31E-03	1.44E-03	1.58E-03	1.75E-03	1.92E-03	2.02E-03	2.59E-03
3 to <6 years	543	2.00E-02	1.53E-02	1.63E-02	1.78E-02	1.98E-02	2.16E-02	2.38E-02	2.59E-02	3.29E-02	1.14E-03	7.92E-04	8.53E-04	9.64E-04	1.11E-03	1.31E-03	1.45E-03	1.56E-03	1.93E-03
6 to <11 years	894	2.10E-02	1.60E-02	1.68E-02	1.85E-02	2.04E-02	2.30E-02	2.61E-02	2.81E-02	4.31E-02	7.23E-04	4.62E-04	5.12E-04	5.98E-04	7.15E-04	8.38E-04	9.42E-04	1.01E-03	1.37E-03
11 to <16 years	1,451	2.36E-02	1.82E-02	1.95E-02	2.08E-02	2.30E-02	2.54E-02	2.84E-02	3.14E-02	4.24E-02	4.41E-04	3.17E-04	3.38E-04	3.80E-04	4.31E-04	4.92E-04	5.51E-04	6.11E-04	9.86E-04
16 to <21 years	1,182	2.32E-02	1.66E-02	1.76E-02	1.96E-02	2.24E-02	2.61E-02	3.03E-02	3.20E-02	5.25E-02	3.65E-04	2.67E-04	2.82E-04	3.10E-04	3.51E-04	4.07E-04	4.63E-04	4.94E-04	6.50E-04
High Intensity (METS > 6.0)																			
Birth to <1 year	79	2.42E-02	1.24E-02	1.33E-02	1.72E-02	2.25E-02	2.93E-02	3.56E-02	4.07E-02	7.46E-02	3.26E-03	2.53E-03	2.62E-03	2.89E-03	3.23E-03	3.63E-03	3.96E-03	4.08E-03	5.02E-03
1 year	55	3.65E-02	2.59E-02	2.62E-02	3.04E-02	3.61E-02	4.20E-02	4.73E-02	4.86E-02	7.70E-02	3.38E-03	2.57E-03	2.75E-03	2.97E-03	3.24E-03	3.71E-03	4.16E-03	4.87E-03	4.88E-03
2 years	130	3.76E-02	2.90E-02	3.05E-02	3.23E-02	3.64E-02	4.08E-02	4.81E-02	5.14E-02	7.30E-02	2.80E-03	2.20E-03	2.31E-03	2.48E-03	2.81E-03	3.13E-03	3.36E-03	3.48E-03	3.88E-03
3 to <6 years	347	3.45E-02	2.70E-02	2.82E-02	3.00E-02	3.33E-02	3.76E-02	4.32E-02	4.47E-02	5.66E-02	1.98E-03	1.36E-03	1.51E-03	1.69E-03	1.90E-03	2.19E-03	2.50E-03	2.99E-03	3.24E-03
6 to <11 years	707	3.94E-02	2.86E-02	3.01E-02	3.37E-02	3.80E-02	4.41E-02	5.05E-02	5.46E-02	8.29E-02	1.33E-03	8.85E-04	9.67E-04	1.12E-03	1.33E-03	1.52E-03	1.72E-03	1.81E-03	2.22E-03
11 to <16 years	1,170	4.66E-02	3.11E-02	3.38E-02	3.88E-02	4.53E-02	5.29E-02	6.08E-02	6.63E-02	1.02E-01	8.79E-04	5.89E-04	6.25E-04	7.12E-04	8.53E-04	1.01E-03	1.18E-03	1.31E-03	2.05E-03
16 to <21 years	887	4.41E-02	2.87E-02	3.06E-02	3.65E-02	4.27E-02	5.02E-02	5.82E-02	6.34E-02	1.09E-01	6.96E-04	4.52E-04	4.96E-04	5.67E-04	6.86E-04	7.93E-04	9.16E-04	1.00E-03	1.50E-03

a An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

N = Number of individuals.

MET = Metabolic equivalent.

Source: U.S. EPA, 2006.

Table 6-15. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age and Gender Categories[a]

AgeGroup	N	Mean	5th	10th	25th	50th	75th	90th	95th	Maximum	N	Mean	5th	10th	25th	50th	75th	90th	95th	Maximum
	Duration (hours/day) Spent at Activity – Males		Percentiles								Duration (hours/day) Spent at Activity – Females		Percentiles							
Sleep or nap (Activity ID = 14500)																				
Birth to <1 year	419	13.51	12.63	12.78	13.19	13.53	13.88	14.24	14.46	15.03	415	12.99	12.00	12.16	12.53	12.96	13.44	13.82	14.07	14.82
1 year	308	12.61	11.89	12.15	12.34	12.61	12.89	13.13	13.29	13.79	245	12.58	11.59	11.88	12.29	12.63	12.96	13.16	13.31	14.55
2 years	261	12.06	11.19	11.45	11.80	12.07	12.39	12.65	12.75	13.40	255	12.09	11.45	11.68	11.86	12.08	12.34	12.57	12.66	13.48
3 to <6 years	540	11.18	10.57	10.70	10.94	11.18	11.45	11.63	11.82	12.39	543	11.13	10.45	10.70	10.92	11.12	11.38	11.58	11.75	12.23
6 to <11 years	940	10.18	9.65	9.75	9.93	10.19	10.39	10.59	10.72	11.24	894	10.26	9.55	9.73	10.01	10.27	10.54	10.74	10.91	11.43
11 to <16 years	1337	9.38	8.84	8.94	9.15	9.38	9.61	9.83	9.95	10.33	1451	9.57	8.82	8.97	9.27	9.55	9.87	10.17	10.31	11.52
16 to <21 years	1241	8.69	7.91	8.08	8.36	8.67	9.03	9.34	9.50	10.44	1182	9.08	8.26	8.44	8.74	9.08	9.39	9.79	10.02	11.11
Sedentary & Passive Activities (METS ≤ 1.5 -- Includes Sleep or Nap)																				
Birth to <1 year	419	14.95	13.82	14.03	14.49	14.88	15.44	15.90	16.12	17.48	415	14.07	12.86	13.05	13.53	14.08	14.54	15.08	15.49	16.14
1 year	308	14.27	13.22	13.33	13.76	14.25	14.74	15.08	15.38	16.45	245	14.32	13.02	13.25	13.73	14.31	14.88	15.36	15.80	16.40
2 years	261	14.62	13.52	13.67	14.11	14.54	15.11	15.60	15.77	17.28	255	14.86	13.81	13.95	14.44	14.81	15.32	15.78	16.03	16.91
3 to <6 years	540	14.12	13.01	13.18	13.54	14.03	14.53	15.26	15.62	17.29	543	14.27	12.88	13.15	13.56	14.23	14.82	15.43	15.85	17.96
6 to <11 years	940	13.51	12.19	12.45	12.86	13.30	13.85	14.82	15.94	19.21	894	13.97	12.49	12.74	13.22	13.82	14.50	15.34	16.36	18.68
11 to <16 years	1337	13.85	12.39	12.65	13.06	13.61	14.30	15.41	16.76	18.79	1451	14.19	12.38	12.76	13.34	14.05	14.82	15.87	16.81	19.27
16 to <21 years	1241	13.21	11.39	11.72	12.32	13.08	13.97	14.83	15.44	18.70	1182	13.58	11.80	12.17	12.79	13.52	14.29	15.08	15.67	16.96
Light Intensity Activities (1.5 < METS ≤ 3.0)																				
Birth to <1 year	419	5.30	2.97	3.25	3.71	4.52	7.29	8.08	8.50	9.91	415	6.00	3.49	3.70	4.26	5.01	8.43	9.31	9.77	10.53
1 year	308	5.52	2.68	2.89	3.37	4.31	8.23	9.04	9.73	10.90	245	5.61	2.83	2.94	3.46	4.39	8.28	9.03	9.39	10.57
2 years	261	5.48	3.06	3.26	3.85	4.58	7.58	8.83	9.04	9.92	255	5.78	3.20	3.54	4.29	5.33	7.48	8.46	8.74	9.93
3 to <6 years	540	6.60	3.86	4.25	5.16	6.20	8.26	9.31	9.70	10.74	543	6.25	3.78	4.10	4.79	5.84	7.86	8.84	9.38	10.32
6 to <11 years	940	7.62	5.07	5.57	6.63	7.63	8.72	9.78	10.12	11.59	894	7.27	4.63	5.46	6.33	7.17	8.34	9.42	9.79	11.06
11 to <16 years	1337	7.50	4.48	5.59	6.75	7.67	8.51	9.19	9.63	10.91	1451	7.55	4.89	5.62	6.75	7.67	8.55	9.27	9.57	10.85
16 to <21 years	1241	7.13	4.37	4.97	6.00	7.02	8.29	9.43	10.03	11.50	1182	6.98	4.60	5.08	5.91	6.85	7.96	9.16	9.57	12.29

Table 6-15. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age and Gender Categories[a] (continued)

Age Group	N	Mean	Duration (hours/day) Spent at Activity – Males: Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum	N	Mean	Duration (hours/day) Spent at Activity – Females: Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Moderate Intensity Activities (3.0 < METS ≤ 6.0)																				
Birth to <1 year	419	3.67	0.63	0.97	1.74	4.20	5.20	5.80	6.21	7.52	415	3.91	0.53	0.74	1.10	4.87	5.77	6.27	6.54	7.68
1 year	308	4.04	0.45	0.59	1.14	5.29	6.06	6.61	6.94	7.68	245	4.02	0.52	0.73	1.08	5.14	6.10	7.00	7.37	8.07
2 years	261	3.83	0.59	0.76	1.23	4.74	5.37	5.82	6.15	7.40	255	3.27	0.50	0.78	1.22	4.01	4.88	5.35	5.57	6.93
3 to <6 years	540	3.15	0.55	0.75	1.30	3.80	4.52	5.11	5.32	6.30	543	3.35	0.70	0.89	1.61	3.88	4.71	5.29	5.65	7.58
6 to <11 years	940	2.66	0.65	0.92	1.65	2.68	3.57	4.36	4.79	5.95	894	2.57	0.65	0.95	1.82	2.66	3.41	3.95	4.32	6.10
11 to <16 years	1337	2.35	0.88	1.09	1.66	2.30	3.02	3.62	3.89	5.90	1451	2.01	0.89	1.08	1.45	1.96	2.51	3.03	3.28	4.96
16 to <21 years	1241	3.35	1.13	1.42	2.19	3.45	4.37	5.24	5.59	6.83	1182	3.26	1.27	1.48	2.21	3.39	4.24	4.74	5.07	6.68
High Intensity (METS > 6.0)																				
Birth to <1 year	183	0.20	0.00	0.00	0.01	0.14	0.28	0.50	0.59	0.96	79	0.17	0.03	0.05	0.09	0.14	0.21	0.33	0.40	0.58
1 year	164	0.31	0.01	0.01	0.03	0.22	0.56	0.78	0.93	1.52	55	0.22	0.03	0.05	0.09	0.18	0.35	0.40	0.43	0.48
2 years	162	0.10	0.00	0.01	0.03	0.05	0.14	0.25	0.33	0.48	130	0.15	0.00	0.01	0.03	0.08	0.16	0.48	0.65	1.01
3 to <6 years	263	0.27	0.02	0.03	0.04	0.13	0.33	0.75	1.16	1.48	347	0.19	0.01	0.02	0.05	0.10	0.22	0.46	0.73	1.43
6 to <11 years	637	0.32	0.01	0.01	0.03	0.13	0.38	1.10	1.50	3.20	707	0.24	0.02	0.03	0.06	0.12	0.26	0.67	0.98	1.71
11 to <16 years	1111	0.38	0.03	0.04	0.10	0.21	0.47	1.03	1.34	2.35	1170	0.30	0.03	0.04	0.08	0.19	0.40	0.66	0.96	3.16
16 to <21 years	968	0.40	0.03	0.04	0.14	0.27	0.53	0.99	1.29	2.59	887	0.24	0.01	0.03	0.08	0.18	0.34	0.51	0.60	1.61

[a] Individual measures are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.
N = Number of individuals.
MET =Metabolic equivalent.

Source: U.S. EPA, 2006.

Table 6-16. Nonnormalized Daily Inhalation Rates (m^3/day) Derived Using Layton's (1993) Method and CSFII Energy Intake Data

Age	Sample Size (Nonweighted)	Mean	SEM	Percentiles 50th	90th	95th	SE of 95th percentile
Infancy							
0-2 months	182	3.63	0.14	3.30	5.44	7.10	0.64
3-5 months	294	4.92	0.14	4.56	6.86	7.72	0.48
6-8 months	261	6.09	0.15	5.67	8.38	9.76	0.86
9-11 months	283	7.41	0.20	6.96	10.21	11.77	-
0-11 months	1,020	5.70	0.10	5.32	8.74	9.95	0.55
Children							
1 year	934	8.77	0.08	8.30	12.19	13.79	0.25
2 years	989	9.76	0.10	9.38	13.56	14.81	0.35
3 years	1,644	10.64	0.10	10.28	14.59	16.03	0.27
4 years	1,673	11.40	0.09	11.05	15.53	17.57	0.23
5 years	790	12.07	0.13	11.56	15.72	18.26	0.47
6 years	525	12.25	0.18	11.95	16.34	17.97	0.87
7 years	270	12.86	0.21	12.51	16.96	19.06	1.27
8 years	253	13.05	0.25	12.42	17.46	19.02	1.08
9 years	271	14.93	0.29	14.45	19.68	22.45[a]	1.35
10 years	234	15.37	0.35	15.19	20.87	22.90[a]	1.02
11 years	233	15.49	0.32	15.07	21.04	23.91[a]	1.62
12 years	170	17.59	0.54	17.11	25.07[a]	29.17[a]	1.61
13 years	194	15.87	0.44	14.92	22.81[a]	26.23[a]	1.11
14 years	193	17.87	0.62	15.90	25.75[a]	29.45[a]	4.38
15 years	185	18.55	0.55	17.91	28.11[a]	29.93[a]	1.79
16 years	201	18.34	0.54	17.37	27.56	31.01	2.07
17 years	159	17.98	0.96	15.90	31.42[a]	36.69[a]	-
18 years	135	18.59	0.78	17.34	28.80[a]	35.24[a]	4.24
Adolescent Boys							
9-18 years	983	19.27	0.28	17.96	28.78	32.82	1.39
Adolescent Girls							
9-18 years	992	14.27	0.22	13.99	21.17	23.30	0.61
U.S. EPA Cancer Guidelines' Age Groups with Greater Weighting							
0 through 1 year	1,954	7.50	0.08	7.19	11.50	12.86	0.17
2 through 15 years	7,624	14.09	0.12	13.13	20.99	23.88	0.50

[a] FASEB/LSRO (1995) convention, adopted by CSFII, denotes a value that might be less statistically reliable than other estimates due to small cell size.
- Denotes unable to calculate.
SEM = Standard error of the mean.
SE = Standard error.

Source: Arcus-Arth and Blaisdell, 2007.

Table 6-17. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Males and Females Combined

Age Group[a]	Sample Size	Mean	95th
Birth to <1 month[b]	182	3.63	7.10
3 to <6 months	294	4.92	7.72
6 to <12 months[c]	544	6.75	10.77
1 to <2 years	934	8.77	13.79
2 to <3 years	989	9.76	14.81
3 to <6 years[d]	4,107	11.37	17.29
6 to <11 years[e]	1,553	13.69	20.28
11 to <16 years[f]	975	17.07	27.74
16 to <21 years[g]	495	18.31	34.32

[a] No other age groups from Table 6-14 (Arcus-Arth and Blaisdell, 2007) fit into the U.S. EPA age groupings.
[b] Age group from Arcus-Arth and Blaisdell (2007) was 0-2 months.
[c] Age groups of 6-8 months and 9-11 months from Arcus-Arth and Blaisdell (2007) were averaged.
[d] Age groups of 3, 4 and 5 years from Arcus-Arth and Blaisdell (2007) were averaged.
[e] Age groups of 6, 7, 8, 9 and 10 years from Arcus-Arth and Blaisdell (2007) were averaged.
[f] Age groups of 11, 12, 13, 14 and 15 years from Arcus-Arth and Blaisdell (2007) were averaged.
[g] Age groups of 16, 17 and 18 years from Arcus-Arth and Blaisdell (2007) were averaged.

Source: Arcus-Arth and Blaisdell, 2007.

Table 6-18. Summary of Institute of Medicine Energy Expenditure Recommendations for Active and Very Active People with Equivalent Inhalation Rates

Age Years	Males		Females	
	Energy Expenditure (kcal/day)	Inhalation Rate (m^3/day)	Energy Expenditure (kcal/day)	Inhalation Rate (m^3/day)
<1	607	3.4	607	3.4
1	869	4.9	869	4.9
2	1050	5.9	977	5.5
3	1,485—1,683	8.4—9.5	1,395—1,649	7.9—9.3
4	1,566—1,783	8.8—10.1	1,475—1,750	8.3—9.9
5	1,658—1,894	9.4—10.7	1,557—1,854	8.8—10.5
6	1,742—1,997	9.8—11.3	1,642—1,961	9.3—11.1
7	1,840—2,115	10.4—11.9	1,719—2,058	9.7—11.6
8	1,931—2,225	10.9—12.6	1,810—2,173	10.2—12.3
9	2,043—2,359	11.5—13.3	1,890—2,273	10.7—12.8
10	2,149—2,486	12.1—14.0	1,972—2,376	11.1—13.4
11	2,279—2,640	12.9—14.9	2,071—2,500	11.7—14.1
12	2,428—2,817	13.7—15.9	2,183—2,640	12.3—14.9
13	2,618—3,038	14.8—17.2	2,281—2,762	12.9—15.6
14	2,829—3,283	16.0—18.5	2,334—2,831	13.2—16.0
15	3,013—3,499	17.0—19.8	2,362—2,870	13.3—16.2
16	3,152—3,663	17.8—20.7	2,368—2,883	13.4—16.3
17	3,226—3,754	18.2—21.2	2,353—2,871	13.3—16.2
18	2,823—3,804	18.4—21.5	2,336—2,858	13.2—16.1
19—30	3,015—3,490	17.0—19.7	2,373—2,683	13.4—15.2
31—50	2,862—3,338	16.2—18.9	2,263—2,573	12.8—14.5
51—70	2,671—3,147	15.1—17.8	2,124—2,435	12.0—13.8

Source: Stifelman, 2007.

Table 6-19. Mean Inhalation Rate Values (m^3/day) for Males, Females, and Males and Females Combined.[a]

Age Group[b]	Males	Females	Combined
Birth to <1 year	3.4	3.4	3.4
1 to <2 years	4.9	4.9	4.9
2 to <3 years	5.9	5.5	5.7
3 to <6 years[c]	9.2	8.3	8.8
6 to <11 years[d]	10.9	10.2	10.6
11 to <16 years[e]	14.9	12.7	13.8
16 to <21 years[f]	18.2	13.3	15.8

[a] Inhalation rates are for IOM Physical Activity Level (PAL) category "active"; the total number of subjects for all PAL categories was 3007.
[b] No other age groups from Table 6-15 (Stifelman, 2007) fit into the EPA age groupings.
[c] Age groups of 3, 4, and 5 years from Stifelman, 2007 were averaged.
[d] Age groups of 6, 7, 8, 9 and 10 years from Stifelman, 2007 were averaged.
[e] Age groups of 11, 12, 13, 14 and 15 years from Stifelman, 2007 were averaged.
[f] Age groups of 16, 17 and 18 years from Stifelman, 2007 were averaged.

Source: Stifelman, 2007.

Table 6-20. Mean Inhalation Rate Values (m^3/day) from Key Studies for Males and Females Combined

Age Group	U.S. EPA (2006)		Brochu et al. (2006)		Arcus-Arth and Blaisdell (2007)		Stifelman (2007)		Combined Key Studies	
	N[a]	Mean	N	Mean	N	Mean	N	Mean	N	Mean
Birth to <1 month	-[b]	-	-	-	182	3.63	-	-	182	3.63
1 to <3 months	-	-	-	-	-	-	-	-	-	-
3 to <6 months	-	-	85	3.32	294	4.92	-	-	379	4.12
6 to <12 months	-	-	103	4.09	544	6.75	-	-	647	5.42
Birth to <1 year	834	8.65	-	-	--	--	-	3.40	834	6.03
1 to <2 years	553	13.40	101	4.95	934	8.77	-	4.90	1,588	8.01
2 to <3 years	516	12.99	-	-	989	9.76	-	5.70	1,505	9.48
3 to <6 years	1,083	12.41	-	-	4,107	11.37	-	8.77	5,190	10.85
6 to <11 years	1,834	12.92	-	-	1,553	13.69	-	10.57	3,387	12.39
11 to <16 years	2,788	14.38	-	-	975	17.07	-	13.78	3,763	15.08
16 to <21 years	2,423	15.41	-	-	495	18.31	-	15.75	2,918	16.48

a Number of individuals; the total number of subjects for Stifelman (2007) was 3,007.
b No data from this study for this age group.

Table 6-21. 95th Percentile Inhalation Rate Values (m^3/day) from Key Studies for Males and Females Combined

Age Group	U.S. EPA (2006)		Brochu et al. (2006)		Arcus-Arth and Blaisdell (2007)		Stifelman (2007)		Combined Key Studies	
	N[a]	95th	N	95th	N	95th	N	95th	N	95th
Birth to <1 month	-[b]	-	-	-	182	7.10	-	-	182	7.10
1 to <3 months	-	-	-	-	-	-	-	-	-	-
3 to <6 months	-	-	85	4.47	294	7.72	-	-	379	6.09
6 to <12 months	-	-	103	5.33	544	10.77	-	-	647	8.05
Birth to <1 year	834	12.68	-	-	-	-	-	-	834	12.68
1 to <2 years	553	18.26	101	6.46	934	13.79	-	-	1,588	12.84
2 to <3 years	516	17.04	-	-	989	14.81	-	-	1,505	15.93
3 to <6 years	1,083	15.17	-	-	4,107	17.29	-	-	5,190	16.23
6 to <11 years	1,834	17.03	-	-	1,553	20.28	-	-	3,387	18.66
11 to <16 years	2,788	19.31	-	-	975	27.74	-	-	3,763	23.53
16 to <21 years	2,423	20.84	-	-	495	34.32	-	-	2,918	27.58

a Number of individuals; the total number of subjects for Stifelman (2007) was 3,007.
b No data from this study for this age group.

Table 6-22. Daily Inhalation Rates Estimated From Daily Activities[a]

Subject	Inhalation Rate (m^3/hour)		Daily Inhalation Rate (DIR)[b] (m^3/day)
	Resting	Light Activity	
Child (10 years)	0.29	0.78	14.8
Infant (1 year)	0.09	0.25	3.76
Newborn	0.03	0.09	0.78

[a] Assumptions made were based on 8 hours resting and 16 hours light activity for adults and children (10 yrs); 14 hours resting and 10 hours light activity for infants (1 yr); 23 hours resting and 1 hour light activity for newborns.

[b]
$$DIR = \frac{1}{T}\sum_{i=1}^{K} IR_i t_i$$

DIR = Daily Inhalation Rate
IR_i = Corresponding inhalation rate at i^{th} activity
t_i = Hours spent during the i^{th} activity
k = Number of activity periods
T = Total time of the exposure period (i.e., a day)

Source: ICRP, 1981.

Table 6-23. Selected Inhalation Rate Values During Different Activity Levels Obtained From Various Literature Sources

Subject	W (kg)	Resting			Light Activity			Heavy Work			Maximal Work During Exercise		
		f	VT	V*	f	VT	V*	f	VT	V*	f	VT	V*
Adolescent													
male, 14-16 y		16	330	5.2							53	2520	113
male, 14-15 y	59.4												
female, 14-16 y		15	300	4.5									
female, 14-15 y; 164.9 cm L	56										52	1870	88
Children													
10 y; 140 cm L		16	300	4.8	24	600	14						
males, 10-11 y	36.5										58	1330	71
males, 10-11 y; 140.6 cm L	32.5										61	1050	61
females, 4-6 y	20.8										70	600	40
females, 4-6 y; 111.6 cm L	18.4										66	520	34
Infant, 1 y		30	48	1.4[a]									
Newborn	2.5	34	15	0.5									
20 hrs-13 wk	2.5-5.3										68[b]	51[a,b]	3.5[b]
9.6 hrs	3.6	25	21	0.5									
6.6 days	3.7	29	21	0.6									

W = Body weights; f = frequency (breaths/min); VT = tidal volume (ml); V* = minute volume (l/min); cm L = length/height; y = years of age; wk = week.

[a] Calculated from V* = f x VT.

[b] Crying.

Source: ICRP, 1981.

Table 6-24. Summary of Human Inhalation Rates for Children by Activity Level (m^3/hour)[a]

	N[b]	Resting[c]	N[b]	Light[d]	N[b]	Moderate[e]	N[b]	Heavy[f]
Child, 6 years	8	0.4	16	0.8	4	2	5	2.3
Child, 10 years	10	0.4	40	1	29	3.2	43	3.9

[a] Values of inhalation rates for children (male and female) presented in this table represent the mean of values reported for each activity level in 1985.
[b] Number of observations at each activity level.
[c] Includes watching television, reading, and sleeping.
[d] includes most domestic work, attending to personal needs and care, hobbies, and conducting minor indoor repairs and home improvements.
[e] Includes heavy indoor cleanup, performance of major indoor repairs and alterations, and climbing stairs.
[f] Includes vigorous physical exercise and climbing stairs carrying a load.

Source: Adapted from U.S. EPA, 1985.

Table 6-25. Activity Pattern Data Aggregated for Three Microenvironments by Activity Level for All Age Groups

Microenvironment	Activity Level	Average Hours Per Day in Each Microenvironment at Each Activity Level
Indoors	Resting	9.82
	Light	9.82
	Moderate	0.71
	Heavy	0.10
	TOTAL	20.4
Outdoors	Resting	0.51
	Light	0.51
	Moderate	0.65
	Heavy	0.12
	TOTAL	1.77
In Transportation Vehicle	Resting	0.86
	Light	0.86
	Moderate	0.05
	Heavy	0.0012
	TOTAL	1.77

Source: Adapted from U.S. EPA, 1985.

Table 6-26. Summary of Daily Inhalation Rates Grouped by Age and Activity Level

Subject	Daily Inhalation Rate (m^3/day)[a]				Total Daily IR[b] (m^3/day)
	Resting	Light	Moderate	Heavy	
Child, 6 years	4.47	8.95	2.82	0.50	16.74
Child, 10 years	4.47	11.19	4.51	0.85	21.02

[a] Daily inhalation rate was calculated using the following equation:

$$IR = \frac{1}{T} \sum_{i=1}^{K} IR_i t_i$$

IR_i = Inhalation rate at i^{th} activity (Table 6-13 and 6-14)
t_i = Hours spent per day during i^{th} activity (Table 6-15)
k = Number of activity periods
T = Total time of the exposure period (e.g., a day)

[b] Total daily inhalation rate was calculated by summing the specific activity (resting, light, moderate, heavy) and dividing them by the total amount of time spent on all activities.

Source: Generated using the data from U.S. EPA (1985) as shown in Tables 6-24 and 6-25.

Table 6-27. Calibration and Field Protocols for Self-monitoring of Activities Grouped by Subject Panels

Panel	Calibration Protocol	Field Protocol
Panel 2 - Healthy Elementary School Students - 5 male, 12 female, ages 10-12	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Saturday, Sunday and Monday (school day) in early autumn; heart rate recordings and activity diary during waking hours and during sleep.
Panel 3 - Healthy High School Students - 7 male, 12 female, ages 13-17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Same as Panel 2, however, no heart rate recordings during sleep for most subjects.
Panel 6 - Young Asthmatics - 7 male, 6 female, ages 11-16	Laboratory exercise tests on bicycles and treadmills	Summer monitoring for 2 successive weeks, including 2 controlled exposure studies with few or no observable respiratory effects.

Source: Linn et al., 1992.

Table 6-28. Subject Panel Inhalation Rates by Mean VR, Upper Percentiles, and Self-estimated Breathing Rates

Panel Number and Description	N[a]	Inhalation Rates (m^3/hour)				
		Mean VR	99th Percentile VR	Mean VR at Activity Levels[b]		
				Slow	Medium	Fast
Healthy						
2 - Elementary School Students	17	0.90	1.98	0.84	0.96	1.14
3 - High School Students	19	0.84	2.22	0.78	1.14	1.62
Asthmatics						
6 - Elementary and High School Students	13	1.20	2.40	1.20	1.20	1.50

[a] Number of individuals in each survey panel.
[b] Some subjects did not report medium and/or fast activity. Group means were calculated from individual means (i.e., give equal weight to each individual who recorded any time at the indicated activity level).
VR = Ventilation rate.

Source: Linn et al., 1992.

Table 6-29. Distribution of Predicted Inhalation Rates by Location and Activity Levels for Elementary and High School Students

Age (years)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hour) Mean ± SD	Percentile Rankings[b] 1st	50th	99.9th
10-12	EL[c] (N[d]=17)	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
			medium	23.6	0.96 ± 0.36	0.24	0.84	2.58
			fast	2.4	1.02 ± 0.60	0.24	0.84	3.42
		Outdoors	slow	8.9	0.96 ± 0.54	0.36	0.78	4.32
			medium	11.2	1.08 ± 0.48	0.24	0.96	3.36
			fast	4.3	1.14 ± 0.60	0.48	0.96	3.60
13-17	HS[c] (N[d]=19)	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
			medium	10.9	0.96 ± 0.42	0.42	0.84	4.02
			fast	1.4	1.26 ± 0.66	0.54	1.08	6.84[e]
		Outdoors	slow	8.2	0.96 ± 0.48	0.42	0.90	5.28
			medium	7.4	1.26 ± 0.78	0.48	1.08	5.70
			fast	1.4	1.44 ± 1.08	0.48	1.02	5.94

[a] Recorded time averaged about 23 hr per elementary school student and 33 hours per high school student over 72-hour periods.

[b] Geometric means closely approximated 50th percentiles; geometric standard deviations were 1.2-1.3 for HR,1.5-1.8 for VR.

[c] Elementary school student or high school student.

[d] Number of students that participated in survey.

[e] Highest single value.

SD = Standard deviation.

Source: Spier et al., 1992.

Table 6-30. Average Hours Spent Per Day in a Given Location and Activity Level for Elementary and High School Students

Students	Location	Activity Level			Total Time Spent (hours/day)
		Slow	Medium	Fast	
Elementary school, ages 10-12 years (N=17)	Indoors	16.3	2.9	0.4	19.6
	Outdoors	2.2	1.7	0.5	4.4
High school, ages 13-17 years (N=19)	Indoors	19.5	1.5	0.2	21.2
	Outdoors	1.2	1.3	0.2	2.7

N = Number of students that participated in survey.

Source: Spier et al., 1992.

Table 6-31. Summary of Average Inhalation Rates (m^3/hour) by Age Group and Activity Levels for Laboratory Protocols

Age Group	Activity Level				
	Resting[a]	Sedentary[b]	Light[c]	Moderate[d]	Heavy[e]
Young Children (3-5.9 years) Average inhalation rate (m^3/hour) (N=12, gender not specified)	0.37	0.40	0.65	DNP[f]	DNP[f]
Children (6-12.9 years) Average inhalation rate (m^3/hour) (N=40, 20 male and 20 female)	0.45	0.47	0.95	1.74	2.23

[a] Resting defined as lying (see Table 6-33 for original data).
[b] Sedentary defined as sitting and standing (see Table 6-33 for original data).
[c] Light defined as walking at speed level 1.5 - 3.0 mph (see Table 6-33 for original data).
[d] Moderate defined as fast walking (3.3 - 4.0 mph) and slow running (3.5 - 4.0 mph) (see Table 6-33 for original data).
[e] Heavy defined as fast running (4.5 - 6.0 mph) (see Table 6-33 for original data).
[f] Group did not perform (DNP) this protocol or N was too small for appropriate mean comparisons. All young children did not run.

Source: Adapted from Adams, 1993.

Table 6-32. Summary of Average Inhalation Rates (m^3/hour) by Age Group And Activity Levels in Field Protocols

Age Group	Moderate Activity[a]
Young Children (3-5.9 years) Average inhalation rate (m^3/hour) (N=12, gender not specified)	0.68
Children (6-12.9 years) Average inhalation rate (m^3/hour) (N=40, 20 male and 20 female)	1.07

[a] Moderate activity was defined as play.
N = Number of individuals.

Source: Adams, 1993.

Table 6-33. Mean Minute Inhalation Rate (m^3/minute) by Group and Activity for Laboratory Protocols

Activity	Young Children[a]	Children[a]
Lying	6.19E-03	7.51E-03
Sitting	6.48E-03	7.28E-03
Standing	6.76E-03	8.49E-03
Walking		
1.5 mph	1.03E-02	DNP[b]
1.875 mph	1.05E-02	DNP
2.0 mph	DNP	1.41E-02
2.25 mph	1.17E-02	DNP
2.5 mph	DNP	1.56E-02
3.0 mph	DNP	1.78E-02
3.3 mph	DNP	DNP
4.0 mph	DNP	DNP
Running		
3.5 mph	DNP	2.68E-02
4.0 mph	DNP	3.12E-02
4.5 mph	DNP	3.72E-02
5.0 mph	DNP	DNP
6.0 mph	DNP	DNP

[a] Young Children, male and female 3-5.9 years old; Children, male and female 6-12.9 years old.
[b] Group did not perform (DNP) this protocol or N was too small for appropriate mean comparisons.

Source: Adams , 1993.

Table 6-34. Mean Minute Inhalation Rate (m^3/minute) by Group and Activity for Field Protocols

Activity	Young Children[a]	Children[a]
Play	1.13E-02	1.89E-02

[a] Young children, male and female 3-5.9 years old; children, male and female 6-12.9 years old.

Source: Adams, 1993.

Table 6-35. Comparisons of Estimated Basal Metabolic Rates (BMR) with Average Food-energy Intakes (EFD) for Individuals Sampled in the 1977-78 NFCS

Cohort/Age (years)	Body Weight (kg)	BMR[a]		Energy Intake (EFD)		Ratio EFD[d]/BMR
		MJ/day[b]	Kcal/day[c]	MJ/day	Kcal/day	
Males and Females						
< 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68
Males						
9 to 11	36	5.42	1293	8.55	2040	1.58
12 to 14	50	6.45	1540	9.54	2276	1.48
15 to 18	66	7.64	1823	10.80	2568	1.41
Females						
9 to 11	36	4.91	1173	7.75	1849	1.58
12 to 14	49	5.64	1347	7.72	1842	1.37
15 to 18	56	6.03	1440	7.32	1748	1.21

[a] Calculated from the appropriate age and gender-based BMR equations given in Table 6-37.
[b] MJ/day - mega joules/day.
[c] Kcal/d - kilo calories/day.
[d] Food energy intake (Kcal/day) or (MJ/day).

Source: Layton, 1993.

Table 6-36. Daily Inhalation Rates Calculated from Food-energy Intakes

Cohort/Age (years)	L[b]	Daily Inhalation Rate[c] (m^3/day)	Sleep (hours)	MET[a] Value		Inhalation Rates	
				A[d]	F[e]	Inactive[f] (m^3/day)	Active[f] (m^3/day)
Males and Females							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 to 2	2	6.8	11	1.6	2.2	4.16	9.15
3 to 5	3	8.3	10	1.7	2.2	4.98	10.96
6 to 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 to 11	3	14	9	1.9	2.5	7.32	18.3
12 to 14	3	15	9	1.8	2.2	8.71	19.16
15 to 18	4	17	8	1.7	2.1	10.31	21.65
Females							
9 to 11	3	13	9	1.9	2.5	6.63	16.58
12 to 14	3	12	9	1.6	2.0	7.61	15.22
15 to 18	4	12	8	1.5	1.7	8.14	13.84

[a] MET = Metabolic equivalent.

[b] L = Number of years for each age cohort.

[a] Daily inhalation rate was calculated by multiplying the EFD values (see Table 6-35) by H × VQ for subjects under 9 years of age and by 1.2 × H × VQ (for subjects 9 years of age and older (see text for explanation), where EFD = Food energy intake (Kcal/day) or (MJ/day), H = Oxygen uptake = 0.05 LO_2/KJ or 0.21 LO_2/Kcal, and VQ = Ventilation equivalent = 27 = geometric mean of VQs (unitless).

[d] For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (Table 6-35) by the factor 1.2 (see text for explanation).

[e] F = (24 × A - S)/(24 - S) (unitless), ratio of the rate of energy expenditure during active hours to the estimated BMR (unitless), where S = Number of hours spent sleeping each day.

[f] Inhalation rate for inactive periods was calculated as BMR × H × VQ, and for active periods by multiplying the inactive inhalation rate by F (see footnote c); BMR values are from Table 6-35, where BMR = basal metabolic rate (MJ/day) or (kg/hr).

Source: Layton, 1993.

Table 6-37. Statistics of the Age/gender Cohorts Used to Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Gender, Age (years)	BMR		CV	Body Weight (kg)	N	BMR Equation[a]	r
	MJ d^{-1}	SD					
Males							
Under 3	1.51	0.92	0.61	6.6	162	0.249 bw - 0.127	0.95
3 to < 10	4.14	0.50	0.12	21	338	0.095 bw + 2.110	0.83
10 to < 18	5.86	1.17	0.20	42	734	0.074 bw + 2.754	0.93
Females							
Under 3	1.54	0.92	0.59	6.9	137	0.244 bw - 0.130	0.96
3 to < 10	3.85	0.49	0.13	21	413	0.085 bw + 2.033	0.81
10 to < 18	5.04	0.78	0.15	38	575	0.056 bw + 2.898	0.8

[a] Body weight (bw) in kg.
SD = Standard deviation.
CV = Coefficient of variation (SD/mean).
N = Number of observations.
r = Coefficient of correlation.

Source: Layton, 1993.

Table 6-38. Daily Inhalation Rates Obtained from the Ratios of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Gender/Age (years)	Body Weight[a] (kg)	BMR[b] (MJ/day)	VQ	A[c]	H (m^3O_2/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Males						
0.5 to <3	14	3.4	27	1.6	0.05	7.3
3 to <10	23	4.3	27	1.6	0.05	9.3
10 to <18	53	6.7	27	1.7	0.05	15
Females						
0.5 to <3	11	2.6	27	1.6	0.05	5.6
3 to <10	23	4.0	27	1.6	0.05	8.6
10 to <18	50	5.7	27	1.5	0.05	12

a Body weight was based on the average weights for age/gender cohorts in the U.S. population.

b The BMRs (basal metabolic rate) are calculated using the respective body weights and BMR equations (see Table 6-36).

c The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Basiotis et al. (1989) study: Male = 1.59, Female = 1.38. For males and females under 10 years old, the mean BMR multiplier used was 1.6. For males and females aged 10 to < 18 years, the mean values for A given in Table 6-36 for 12-14 years and 15-18 years, age brackets for males and females were used: male = 1.7 and female = 1.5.

d Inhalation rate = BMR x A x H x VQ; VQ = ventilation equivalent and H = oxygen uptake.

Source: Layton, 1993.

Table 6-39. Inhalation Rates for Short-term Exposures

Gender/Age (years)	Body Weight (kg)[a]	BMR[b] (MJ/day)	Activity Type: Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier)				
			1	1.2	2[c]	4[d]	10[e]
			Inhalation Rate (m^3/minute)[f,g]				
Males							
0.5 to <3	14	3.40	3.2E-03	3.8E-03	6.4E-03	1.3E-02	–[h]
3 to <10	23	4.30	4.0E-03	4.8E-03	8.1E-03	1.6E-02	–[h]
10 to <18	53	6.70	6.3E-03	7.5E-03	1.3E-02	2.5E-02	6.3E-02
Females							
0.5 to <3	11	2.60	2.4E-03	2.9E-03	4.9E-03	1.0E-02	–[h]
3 to <10	23	4.00	3.8E-03	4.5E-03	7.5E-03	1.5E-02	–[h]
10 to <18	50	5.70	5.3E-03	6.4E-03	1.1E-02	2.1E-02	5.3E-02

a Body weights were based on average weights for age/gender cohorts of the U.S. population

b The BMRs for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Table 6-37).

c Range = 1.5 - 2.5.

d Range = 3 - 5.

e Range = >5 - 20.

f The inhalation rate was calculated as IR = BMR (MJ/day) × H (0.05 L/KJ) × MET × VQ (27) × (day/1440 min)

g Original data were presented in L/min. Conversion to m^3/min was obtained as follows: $\frac{m^3}{1000L} \times \frac{L}{min}$

h The maximum possible MET sustainable for more than 5 minutes does not reach 10 for females and males until age 13 and 12, respectively. Therefore, a METs of 10 is not possible for this age category.

Source: Layton, 1993.

Table 6-40. Mean, Median, and SD of Inhalation Rate According to Waking or Sleeping in 618 Infants and Children Grouped in Classes of Age

Age (months)	N	Inhalation Rate (breaths/min)			
		Waking		Sleeping	
		Mean ± SD	Median	Mean ± SD	Median
<2	104	48.0 ± 9.1	47	39.8 ± 8.7	39
2 to <6	106	44.1 ± 9.9	42	33.4 ± 7.0	32
6 to <12	126	39.1 ± 8.5	38	29.6 ± 7.0	28
12 to <18	77	34.5 ± 5.8	34	27.2 ± 5.6	26
18 to <24	65	32.0 ± 4.8	32	25.3 ± 4.6	24
24 to <30	79	30.0 ± 6.2	30	23.1 ± 4.6	23
30 to 36	61	27.1 ± 4.1	28	21.5 ± 3.7	21

SD = Standard deviation.
N = Number of individuals.

Source: Rusconi et al., 1994.

Figure 6-1. 5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Awake Subjects (RR = respiratory rate). Source: Rusconi et al., 1994.

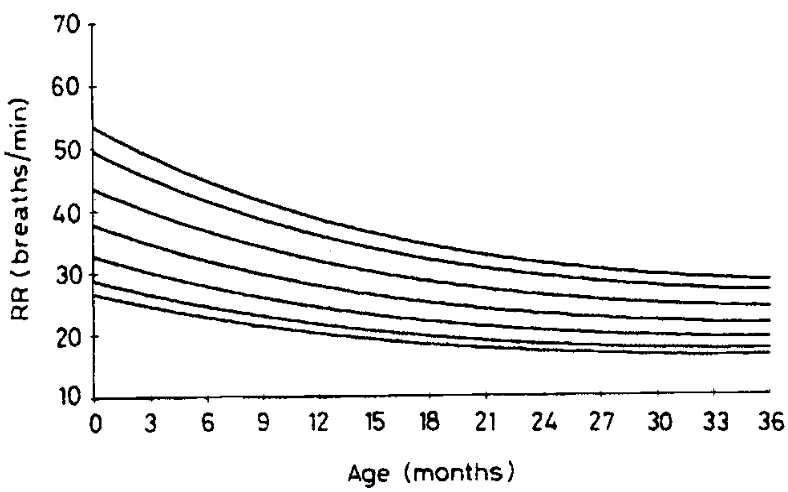

Figure 6-2. 5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Asleep Subjects (RR = respiratory rate). Source: Rusconi et al., 1994.