

A Monte Carlo Approach to Generating Equivalent Ventilation Rates in Population Exposure Assessments

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API PUBLICATION NUMBER 4617

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This report describes a research project conducted by IT Air Quality Services (ITAQS) for the American Petroleum Institute (API). The project consisted of eight work elements:

1. acquisition of four time/activity databases in which each documented diary event is associated with a measured pulse rate,
2. acquisition of clinical data relating subject pulse rate to ventilation rate,
3. statistical analysis of clinical data to determine appropriate procedures for converting pulse rate to equivalent ventilation rate (EVR),
4. conversion of each pulse-rate database into a corresponding database listing EVR by diary event,
5. statistical analysis of each EVR database to identify factors that affect EVR,
6. development of algorithms for predicting EVR according to population group,
7. testing of each algorithm by comparing model predictions with measured EVR values, and
8. preparation of this report.

Mike McCoy was the ITAQS project manager for the overall project and was primarily responsible for work elements 1, 2, 4, and 7. Ted Johnson was ITAQS technical director for the project and had primary responsibility for work elements 3, 5, 6, and 8. Doug Brinson assisted with work element 3. Joan Abernethy typed the report.

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ABSTRACT

A number of researchers have developed computer-based models for simulating the exposure of human populations to air pollution. The probabilistic version of the National Ambient Air Quality Standards Exposure Model (pNEM) is typical of these models in that it characterizes each exposure by time period and pollutant concentration. Unlike most other exposure models, pNEM also characterizes each exposure by a measure of respiration, the equivalent ventilation rate (EVR). EVR is defined as ventilation rate divided by body surface area. In the current version of pNEM, EVR is determined by an algorithm that randomly selects values from lognormal distributions that are specific to age and breathing rate category. A research team directed by Jack Hackney and William Linn conducted four studies in Los Angeles which used time/activity diaries and heart rate monitors to obtain ventilation rate data representative of typical daily activities. IT Air Quality Services acquired the four Hackney/Linn databases and converted each into a file of EVR values, one EVR value for each diary event. Researchers analyzed these files and developed a series of algorithms for generating EVR values that are superior to those used in the current pNEM methodology. Each algorithm uses Monte Carlo (probabilistic) techniques to produce EVR values that vary according to age, gender, activity, breathing rate category (slow, medium, or fast), microenvironment, time of day, activity duration, and other variables present in the input time/activity data files. The algorithms were tested by applying them to representative time/activity databases that contained a measured EVR value for each diary record. In each test, analysts compared the distribution of generated EVR values with the corresponding distribution of measured EVR values. Results of these tests suggest that the algorithms produce realistic EVR distributions.

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) has developed the pNEM methodology as a means of evaluating current and proposed National Ambient Air Quality Standards (NAAQS). The pNEM approach provides exposure estimates for defined population groups based on activity data specific to each group. Similar to other exposure models, pNEM characterizes each exposure event by time period and pollutant concentration. Unlike most other exposure models, pNEM also characterizes each exposure event by equivalent ventilation rate (EVR), defined as ventilation rate divided by body surface area (BSA).

This report presents a series of algorithms that can be used by pNEM and similar models to estimate EVR values by exposure event. Each algorithm is optimized for use with one of four specific data types. The algorithms were developed through an analysis of data reported by a research team directed by Jack Hackney and William Linn. The Hackney/Linn team conducted four studies in Los Angeles to obtain ventilation rate data representative of typical daily activities (elementary school students, high school students, outdoor workers, and construction workers). The heart rate of each study subject was continuously monitored as the subject documented his or her activities in a special diary. Separate clinical trials were conducted in which the heart rate and ventilation rate of each subject were measured simultaneously. These measurements were used to develop a "calibration curve" for each subject relating heart rate to ventilation rate.

Existing calibration curves for three studies (elementary school, high school, and outdoor workers) were used to convert one-minute heart rate measurements into one-minute ventilation rates. The ventilation rate values were in turn divided by the subject's estimated body surface area to produce one-minute EVR values.

ES-1

Hackney and Linn did not provide calibration curves for the construction worker study. An analysis of the applicable calibration data collected during the construction worker study produced two alternative sets of calibration curves, one based on a linear relationship (Model A) and the other on a log-log relationship (Model C). Each set of calibration curves was used to convert one-minute heart rate values into corresponding one-minute ventilation rates. The results were averaged to produce a final set of one-minute ventilation rates. The values were then divided by body surface area to produce a database listing one-minute EVR values for the construction workers.

Algorithms for predicting EVR were developed by applying a four-step procedure to each of the one-minute EVR databases. In Step 1, ITAQS processed each one-minute EVR database to produce a special "event EVR file." Each file provided a sequence of exposure events keyed to the activities documented by each subject. The listing for each event included the average EVR for the event and the values of 20 variables which were considered likely to influence EVR values.

In Step 2, ITAQS prepared tables of descriptive statistics for event EVR values which had been categorized by breathing rate, activity, microenvironment, time of day, and event duration. These statistics provided an initial means for identifying factors to be considered in developing the EVR prediction algorithms. These factors were compiled into sets of candidate variables, each set specific to a particular database type.

In Step 3, ITAQS developed one or more Monte Carlo models for each database type. Each model was specific to one of the following four demographic groups: elementary students, high school students, outdoor workers, and construction workers. Each model consisted of an algorithm capable of generating an EVR for each event in a time/activity data set of the specified database type and

demographic group. Each algorithm predicted EVR as a function of six or more predictor variables which constituted a predictor set.

Each predictor set was developed by first defining a candidate variable set for the database type and then performing stepwise linear regression analyses to determine which of the candidate variables were significant predictors of EVR for a particular demographic group. The regression analyses were performed on the Hackney/Linn databases, as these were the only databases available which provided a "measured" EVR value for each exposure event. The results of the regression analyses determined the variables to be included in the predictor set and the coefficients of various terms in the associated Monte Carlo model.

The best overall predictor variable was found to be LGM, the natural logarithm of the geometric mean of all event EVR values associated with a subject. Statistical analysis of the LGM values indicated that the distribution of LGM values was approximately normal.

In addition to LGM, the regression analyses suggested that variables associated with microenvironment, daytime activities, the exertion level of activities, day of week, breathing rate, and duration of activity were generally useful in predicting event EVR. It should be noted that the duration variables were among the least significant of these predictors.

Each regression analysis produced a set of residual values, one for each EVR value. Statistical analysis of the residuals indicated that (1) the standard deviation of the residuals varied significantly from subject to subject and (2) the distribution of the subject-specific standard deviations was approximately lognormal.

In Step 4, ITAQS performed an initial validation of the Monte Carlo approach by applying the EVR-generator algorithm to each of the four Hackney/Linn databases.

Each application produced a distribution of event EVR values that could be compared with the distribution of "measured" values. For three of the databases (elementary school, high school, and construction workers), the modeled and observed distributions compared favorably with respect to mean, standard deviation, and percentiles up to the 99th or 99.5th percentiles. At higher percentiles, the algorithm tended to underestimate EVR for the elementary and high school databases and over estimate EVR for the construction worker database.

The algorithm did not perform as well for the outdoor worker database. In this case, the model significantly underestimated the standard deviation and the percentiles above the 90th percentile. Analysts found that the differences between modeled and observed distributions were significantly reduced when a particular atypical subject was removed from the analysis. Removal of atypical subjects did not account for all of the differences between the modeled and observed results, however.

Section 1

INTRODUCTION

During the past 15 years, a number of researchers have developed computer-based models for simulating the exposure of human populations to air pollution. These models are frequently used to estimate exposures under various regulatory control scenarios. For example, the U.S. Environmental Protection Agency (EPA) has developed an exposure model specifically to evaluate current and proposed National Ambient Air Quality Standards (NAAQS). A recent version of this model incorporating stochastic features (the probabilistic NAAQS Exposure Model or pNEM) has been used to estimate the exposures of urban populations to ozone^{1,2} and carbon monoxide³.

The pNEM approach provides exposure estimates for defined population groups based on activity data specific to each group. Similar to other exposure models, pNEM characterizes each exposure by time period and pollutant concentration. Unlike most other exposure models, pNEM also characterizes each exposure by a measure of respiration, the equivalent ventilation rate (EVR). EVR is defined as ventilation rate (liters per minute) divided by body surface area (square meters). Clinical research by EPA suggests that EVR exhibits less interpersonal variability than ventilation rate for a given level of exertion⁴.

In pNEM, EVR values vary according to specified lognormal distributions with the constraint that EVR must not exceed a specific upper limit. The limit is assumed to vary with age, gender, and activity duration. A report by Johnson et al.¹ describes the most recent version of the algorithm that is used to determine the limiting values for EVR. A preliminary version of this algorithm was described by Johnson et al. in a report for the American Petroleum Institute⁵.

In a typical application of pNEM, the population of a designated study area is divided into homogenous population groups called cohorts. Using a special file containing empirical activity diary data, the model generates a distinct activity pattern for each cohort. The pattern consists of a sequence of "exposure events". Each event assigns to the cohort a specific environmental setting and a specific breathing rate category. The environmental setting is characterized by geographic location (e.g., within 5 km of a fixed-site monitor) and a microenvironment (e.g., outdoors within 10 m of a road). Using ambient fixed-site monitoring data appropriate to the geographic location and a mass balance model to adjust monitored concentrations to the microenvironment, pNEM provides an estimate of the pollutant concentration associated with each exposure event.

In addition to the environmental setting, each exposure event assigns to the cohort one of four breathing rate categories: sleeping, slow, medium, and fast. These categories were selected to permit use of activity diary data collected during the Cincinnati Activity Diary Study⁶. In this study, over 900 subjects completed three-day time/activity diaries which used these breathing categories to characterize the exertion level associated with each activity.

During a three-year period (1989 to 1991), a research team directed by Jack Hackney and William Linn conducted four studies in Los Angeles to obtain ventilation rate data representative of typical daily activities.^{7,8,9} The heart rate of each study subject was continuously monitored as the subject documented his or her activities in an activity diary similar to that used in the Cincinnati study. Separate clinical trials were conducted in which the heart rate and ventilation rate of each subject were measured simultaneously. These measurements were used to develop a subject-specific "calibration curve" relating heart rate to ventilation rate.

Using this calibration curve, researchers can transform each heart rate measurement into an estimated ventilation rate. The ventilation rates for each

subject can then be converted to corresponding EVR estimates by dividing by the subject's body surface area. Each of the resulting EVR values can be indexed according to the diary entries made by the subject for the associated time period. The EVR values can also be indexed by the subject's demographic characteristics (age, gender, etc.).

The four Hackney/Linn studies produced databases ideally suited for analyzing the relationships between activity diary entries and EVR. Under a contract with the American Petroleum Institute, IT Air Quality Services (ITAQS) acquired the four Hackney/Linn databases and converted each database into a file of EVR values, one EVR value per diary "event." ITAQS analyzed these EVR files and developed a series of algorithms that could be used to generate EVR values in pNEM and similar exposure models. Each algorithm uses Monte Carlo techniques to produce EVR values that vary according to diary entries and subject characteristics.

This report summarizes these research efforts by ITAQS. Section 2 describes the construction of the event EVR files. Section 3 provides descriptive statistics for EVR values classified according to breathing rate category (sleeping, slow, medium, or fast), activity, microenvironment, time of day and duration. Section 4 presents EVR-generating algorithms appropriate for various types of databases. Initial efforts to validate these algorithms are described in Section 5. Section 6 presents a summary of the report and recommendations for further research.

Section 2

CONSTRUCTION OF EVENT EVR FILES

ACQUISITION OF HACKNEY/LINN DATA SETS

ITAQS acquired data from four studies conducted by a research team under the guidance of Jack Hackney and William Linn. These studies, hereafter referred to as the "Hackney/Linn" studies, are identified according to the demographic characteristics of the subjects:

1. Elementary school students⁷
2. High school students⁷
3. Outdoor workers⁸
4. Construction workers⁹

Table 2-1 provides descriptive information concerning each study. Additional information concerning these studies can be found in the paper by Johnson, McCoy, Capel, Wijnberg, and Ollison included in Appendix A.

Each of the Hackney/Linn data sets contained a series of one-minute heart rate (MINHR) values measured during a period documented by a time/activity diary. The diary provided information concerning the subject's location, breathing rate category, and activity during each one-minute interval. Associated with each MINHR value is a one-minute ventilation rate value (MINVR) estimated through the use of a subject-specific calibration curve. ITAQS also developed a demographic profile (age, occupation, etc.) for each subject based on data from background questionnaires administered during each study.

Table 2-1. Characteristics of four time/activity studies conducted by the Hackney/Linn research team.

Study	Characteristics of subjects	Number of subject-days	Study calendar periods	Diary type	Nominal diary time period	Breathing rates reported?	Source of calibration curves
Los Angeles - elem. school	Elementary school students, 10 to 12 years	58	Oct. 1989	Real-time ^a	Midnight to midnight	Yes	Linn
Los Angeles - high school	High school students, 13 to 17 years	66	Sept. and Oct. 1990	Real-time ^a	Midnight to midnight	Yes	Linn
Los Angeles - outdoor worker	Adult outdoor workers, 19 to 50 years	60	Summer 1989	Real-time ^a	Midnight to midnight	Yes	Linn
Los Angeles - construction	Construction workers, 23 to 42 years	19	July - Nov. 1991	Real-time ^a	Subject wake up to subject returns home from work	Yes	ITAQS ^b

^aStudy employed the Cincinnati diary format.^bSee Section 2 of this report.

Before beginning an analysis of the four data sets, ITAQS conferred with Linn to determine whether they had the most recent version of each data set. Linn confirmed that ITAQS had the most recent versions of the data sets associated with the elementary school, high school, and outdoor worker studies. He recommended that ITAQS independently develop a calibration model for the construction workers based on the reported calibration data. The results of ITAQS efforts to develop this model are discussed in the next section of this report.

DEVELOPMENT OF CALIBRATION CURVES FOR CONSTRUCTION WORKERS

Linn provided ITAQS with his best estimates of the one-minute EVR values for three of the four Hackney/Linn studies: elementary school, high school, and outdoor workers. It is important to note that the EVR values in these data sets were not measured directly. As indicated above, measured MINHR values were converted to MINVR through the use of subject-specific calibration curves. Each MINVR was divided by the subject's estimated BSA to produce a corresponding one-minute EVR value.

The calibration curves used in the three studies were all in the form:

$$\ln(\text{MINVR}) = a_0 + (a_1)(\text{MINHR}). \quad (1)$$

The parameters of each curve were determined by fitting Equation 1 to subject-specific data sets obtained from clinical tests. In these tests, MINVR and MINHR were measured simultaneously while the subject exercised at varying levels of exertion.

Equation 1 is a "log-linear" relationship. Raizenne and Spengler¹⁰ have also used log-linear relationships as the basis for calibration curves to convert heart rate to ventilation rate.

Linn did not provide ITAQS with "best estimate" EVR values for the construction worker data set. He indicated to ITAQS that he was dissatisfied with the results of his initial attempts to develop calibration curves for these data. Linn recommended that ITAQS evaluate a variety of relationships and select one which appeared to produce reasonable ventilation estimates throughout the range of measured MINHR values. Table 2-2 presents descriptive statistics, including minimum and maximum values, for the MINHR values measured during the activity diary phase of the construction worker study.

ITAQS acquired the calibration data for the construction workers and attempted to fit each of the following four models to the data for each subject.

$$\text{A. Linear: MINVR} = a_0 + (a_1)(\text{MINHR}) \quad (2)$$

$$\text{B. Quadratic: MINVR} = a_0 + (a_1)(\text{MINHR}) + (a_2)(\text{MINHR})^2 \quad (3)$$

$$\text{C. Log-log: } \ln(\text{MINVR}) = a_0 + (a_1)[\ln(\text{MINHR})] \quad (4)$$

$$\text{D. Log-linear: } \ln(\text{MINVR}) = a_0 + (a_1)(\text{MINHR}) \quad (5)$$

In these models, MINVR is minute ventilation rate and MINHR is minute heart rate.

Linear regression analysis was used to fit each of the four models to the calibration data for each subject. In each analysis, the parameter on the left side of the equals sign was considered the dependent variable. The parameter on the right side was considered the independent variable. For example, $\ln(\text{MINVR})$ and $\ln(\text{MINHR})$ were the dependent and independent variables, respectively, of the regression equation whenever the log-log model (C) was fit to data.

Table 2-2. Descriptive statistics for minute heart rate values measured during the activity diary phase of construction worker study.

PID	Number of heart rate measurements	Measured minute heart rate, beats/min				
		Arithmetic		Minimum	Median	Maximum
		Mean	Std. dev.			
1761	548	88	12.6	53	86	155
1763	270	98	12.3	69	99	130
1764	584	69	9.9	42	68	133
1765	446	91	22.6	40	91	168
1766	729	83	9.4	63	82	139
1767	558	78	20.8	40	79	183
1768	735	74	14.2	45	73	154
1769	638	100	20.6	66	96	197
1770	644	88	17.3	50	87	144
1771	595	109	17.4	62	112	142
1772	616	109	15.5	60	110	160
1773	687	100	17.3	69	98	154
1774	214	95	18.1	67	91	181
1775	651	99	16.1	57	100	141
1776	624	95	15.8	61	96	142
1778	641	100	16.0	63	100	159
1779	146	111	12.7	87	110	164
1780	529	88	10.5	61	89	121
1781	615	85	12.3	54	86	120

Regression analyses based on Models A, C, and D produced estimates of two regression coefficients: a_0 and a_1 . Three regression coefficients were obtained from analyses using Model B (a_0 , a_1 , and a_2). Table 2-3 lists the values of these coefficients for each combination of subject and model. The table also provides a goodness-of-fit statistic for each fit.

The goodness-of-fit statistic is the R^2 value obtained from a regression analysis of measured MINVR values versus predicted MINVR values. The predicted MINVR values were determined by substituting each measured MINHR value into the specified model and using the model to calculate a corresponding MINVR value.

For the majority of subjects, the quadratic model (Model B) yielded the best goodness-of-fit value of the four tested models. This result was expected, as the quadratic is the only model tested that has three regression coefficients. The additional coefficient in the quadratic equation improves the model's ability to fit data.

The two-coefficient models (A,C, or D) are preferable as the basis for constructing calibration curves, as these models are more likely to produce relationships between MINVR and MINHR that increase monotonically throughout the range of applied MINHR values. If the three-coefficient quadratic (Model B) is excluded from consideration, the subject-specific breakdown of the best and worst-fitting models is as follows:

<u>Model</u>	<u>Best fit</u>	<u>Worst Fit</u>
Model A (linear)	5	10
Model C (log-log)	9	0
Model D (log-linear)	6	10

Note that Model C (the log-log model) provides the greatest number of "best" fits (9) among the 20 subjects and the smallest number of "worst" fits (0) of the three models.

Table 2-3. Results of fitting four general models to the construction worker calibration data.

PID	Model	Regression results						Goodness of fit statistic
		a ₀		a ₁		a ₂		
		Value	p	Value	p	Value	p	
1761	A	-52.01	0.0000	0.87	0.0000	-	-	0.8998
	B	14.34	0.7979	-0.64	0.6144	0.0084	0.2428	0.9082
	C	-11.21	0.0000	3.20	0.0000	-	-	0.9066 ^a
	D	-0.091	0.7571	0.0361	0.0000	-	-	0.8984 ^b
1763	A	-58.99	0.0000	0.86	0.0000	-	-	0.9356 ^b
	B	26.76	0.5661	-0.94	0.3402	0.0093	0.0764	0.9468
	C	-13.34	0.0000	3.60	0.0000	-	-	0.9451 ^a
	D	-0.536	0.0141	0.0376	0.0000	-	-	0.9379
1764	A	-40.28	0.0000	0.95	0.0000	-	-	0.9036 ^b
	B	85.45	0.0135	-2.61	0.0083	0.0247	0.0008	0.9514
	C	-6.76	0.0000	2.36	0.0000	-	-	0.9320
	D	0.877	0.0000	0.0334	0.0000	-	-	0.9450 ^a
1765	A	-36.88	0.0000	0.72	0.0000	-	-	0.9502 ^b
	B	21.61	0.2050	-0.53	0.1437	0.0064	0.0014	0.9661
	C	-6.44	0.0000	2.16	0.0000	-	-	0.9642 ^a
	D	1.183	0.0000	0.0228	0.0000	-	-	0.9633
1766	A	-56.30	0.0000	0.91	0.0000	-	-	0.8861 ^a
	B	-39.78	0.6325	0.55	0.7556	0.0019	0.8415	0.8864
	C	-10.81	0.0000	3.10	0.0000	-	-	0.8812
	D	0.178	0.4658	0.0328	0.0000	-	-	0.8740 ^b
1767	A	-9.81	0.0002	0.44	0.0000	-	-	0.9135 ^b
	B	27.98	0.0062	-0.49	0.0419	0.0054	0.0004	0.9465
	C	-2.43	0.0000	1.29	0.0000	-	-	0.9222
	D	1.930	0.0000	0.0158	0.0000	-	-	0.9405 ^a
1768	A	-23.93	0.0000	0.57	0.0000	-	-	0.9477 ^a
	B	-28.93	0.0144	0.67	0.0043	-0.0005	0.6452	0.9481
	C	-4.74	0.0000	1.78	0.0000	-	-	0.9359
	D	1.684	0.0000	0.0171	0.0000	-	-	0.8929 ^b
1769	A	-66.58	0.0000	1.07	0.0000	-	-	0.9713
	B	-7.62	0.6403	-0.17	0.6097	0.0062	0.0009	0.9810
	C	-11.16	0.0000	3.20	0.0000	-	-	0.9761 ^a
	D	0.237	0.1667	0.0326	0.0000	-	-	0.9620 ^b
1770	A	-17.80	0.0000	0.49	0.0000	-	-	0.8530 ^b
	B	44.93	0.0287	-1.01	0.0374	0.0088	0.0030	0.8946
	C	-4.19	0.0000	1.66	0.0000	-	-	0.8692
	D	1.447	0.0000	0.0200	0.0000	-	-	0.8852 ^a

(continued)

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Table 2-3 (Continued)

PID	Model	Regression results						Goodness of fit statistic
		a_0		a_1		a_2		
		Value	p	Value	p	Value	p	
1771	A	-76.52	0.0000	0.93	0.0000	-	-	0.8414 ^a
	B	-262.20	0.0033	4.34	0.0070	-0.0155	0.0297	0.8673
	C	-20.94	0.0000	5.12	0.0000	-	-	0.7581
	D	-1.994	0.0003	0.0461	0.0000	-	-	0.7327 ^b
1772	A	-64.17	0.0000	0.93	0.0000	-	-	0.9587 ^b
	B	42.17	0.2190	-1.06	0.1000	0.0091	0.0036	0.9700
	C	-9.71	0.0000	2.83	0.0000	-	-	0.9692 ^a
	D	0.660	0.0000	0.0263	0.0000	-	-	0.9668
1773	A	-41.93	0.0000	0.66	0.0000	-	-	0.9341 ^a
	B	-83.84	0.0021	1.48	0.0045	-0.0039	0.0962	0.9409
	C	-10.17	0.0000	2.89	0.0000	-	-	0.8988
	D	0.327	0.1008	0.0277	0.0000	-	-	0.8699 ^b
1774	A	-15.63	0.0000	0.44	0.0000	-	-	0.9483 ^b
	B	20.09	0.0017	-0.29	0.0205	0.0036	0.0000	0.9792
	C	-3.39	0.0000	1.46	0.0000	-	-	0.9636
	D	1.806	0.0000	0.0150	0.0000	-	-	0.9784 ^a
1775	A	-76.98	0.0000	1.05	0.0000	-	-	0.8143 ^a
	B	-7.87	0.9038	-0.40	0.7684	0.0075	0.2880	0.8221
	C	-21.19	0.0000	5.28	0.0000	-	-	0.8010
	D	-2.385	0.0000	0.0544	0.0000	-	-	0.7876 ^b
1776	A	-45.23	0.0000	0.75	0.0000	-	-	0.8076 ^b
	B	42.54	0.1752	-0.95	0.1145	0.0077	0.0068	0.8556
	C	-6.74	0.0006	2.16	0.0000	-	-	0.8442
	D	1.057	0.0066	0.0209	0.0000	-	-	0.8548 ^a
1777 ^c	A	-68.62	0.0000	0.80	0.0000	-	-	0.9629 ^b
	B	24.39	0.1509	-0.73	0.0114	0.0061	0.0000	0.9832
	C	-14.21	0.0000	3.63	0.0000	-	-	0.9814 ^a
	D	-0.421	0.0196	0.0292	0.0000	-	-	0.9701
1778	A	-49.25	0.0000	0.86	0.0000	-	-	0.8739
	B	-1.71	0.9578	-0.15	0.8253	0.0052	0.1433	0.8837
	C	-8.08	0.0000	2.53	0.0000	-	-	0.8815 ^a
	D	0.826	0.0000	0.0269	0.0000	-	-	0.8565 ^b
1779	A	-41.42	0.0000	0.77	0.0000	-	-	0.9828
	B	-11.08	0.2628	0.17	0.3902	0.0029	0.0037	0.9875
	C	-6.62	0.0000	2.20	0.0000	-	-	0.9862 ^a
	D	1.323	0.0000	0.0215	0.0000	-	-	0.9730 ^b

(continued)

2-8

Table 2-3 (Continued)

PID	Model	Regression results						Goodness of fit statistic
		a ₀		a ₁		a ₂		
		Value	p	Value	p	Value	p	
1780	A	-40.68	0.0000	0.79	0.0000	-	-	0.8980 ^b
	B	100.76	0.0000	-2.29	0.0000	0.0163	0.0000	0.9832
	C	-5.98	0.0000	2.08	0.0000	-	-	0.9388
	D	1.277	0.0000	0.0229	0.0000	-	-	0.9649 ^a
1781	A	-25.39	0.0000	0.56	0.0000	-	-	0.8831
	B	-10.22	0.6868	0.23	0.6805	0.0018	0.5453	0.8847
	C	-6.05	0.0000	2.05	0.0000	-	-	0.8838 ^a
	D	1.158	0.0000	0.0220	0.0000	-	-	0.8809 ^b

^aBest fit (excluding Model B).^bWorst fit.^cNo activity diary data available.

To assist in selecting a reasonable general model to be applied to all subjects, ITAQS developed calibration curves for subjects characterized by good, average, and poor fits. Figure 2-1 presents the calibration curves for Subject No. 1779 produced by Models A, C, and D when MINHR is varied from 75 to 175 beats/minute. This subject was associated with high goodness-of-fit statistics (0.9730 to 0.9875) for all four models. Figure 2-2 presents calibration curves for Subject No. 1766 when MINHR is varied from 50 to 150 beats/minute. Subject No. 1766 was associated with average goodness-of-fit statistics (0.8812 to 0.8864) for the four models. The lowest goodness-of-fit statistics were associated with Subject No. 1771 (0.7327 to 0.8673). Figure 2-3 provides calibration curves for this subject when MINHR is varied from 50 to 150 beats/minute. Note that the range of MINHR values appearing in each figure approximates the range of MINHR values measured during the activity diary phase of the study (Table 2-2).

Ideally, the calibration curve selected for a subject should produce an estimate of ventilation rate (V_e) at maximum aerobic power (MAP) that is typical of persons of the same age and gender. ITAQS estimated a theoretical value for V_e at MAP for each subject using the following procedure:

1. Determine the subject's age and gender. (Note: the three subjects in this exercise are males aged 31 to 40.)
2. Use the relationship presented in Figure 9-14 of Astrand and Rodahl¹¹ to estimate MINHR at MAP for indicated age and gender.
3. Use the relationship presented in Figure 10-11 of Astrand and Rodahl to estimate the oxygen uptake rate (VO_2) at MAP for the indicated heart rate.
4. Use Table 3 (males) or Table 4 (females) in an unpublished paper by Johnson and Adams (Appendix B) to estimate the V_e -to- VO_2 ratio at MAP.
5. Multiply the VO_2 value determined in Step 3 by the V_e -to- VO_2 ratio determined in Step 4 to estimate MINVR at MAP.

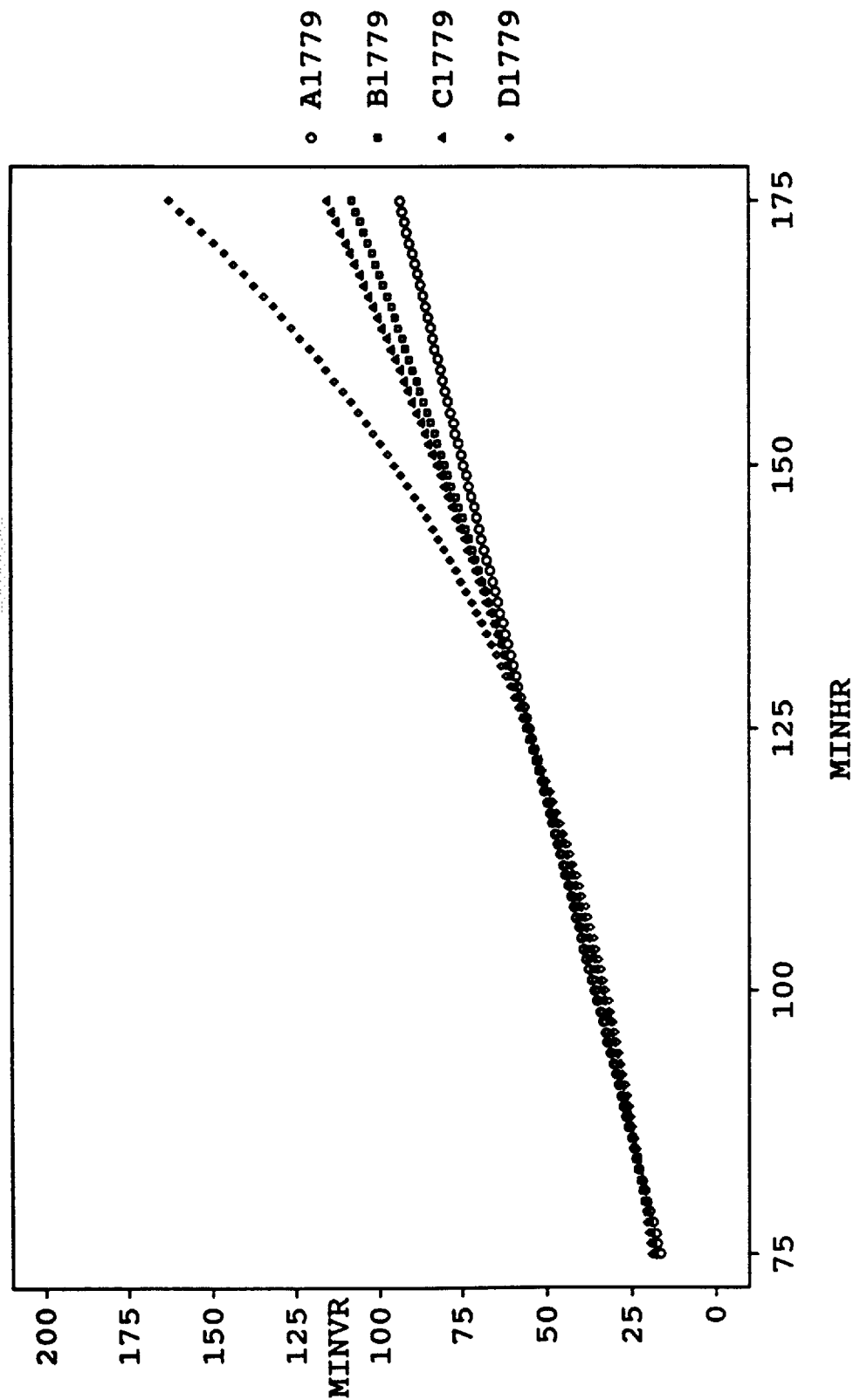


Figure 2-1. Calibration curves relating minute ventilation rate (MINVR) to minute heart rate (MINHR) developed for Subject No. 1779 through the use of Models A, B, C, and D.

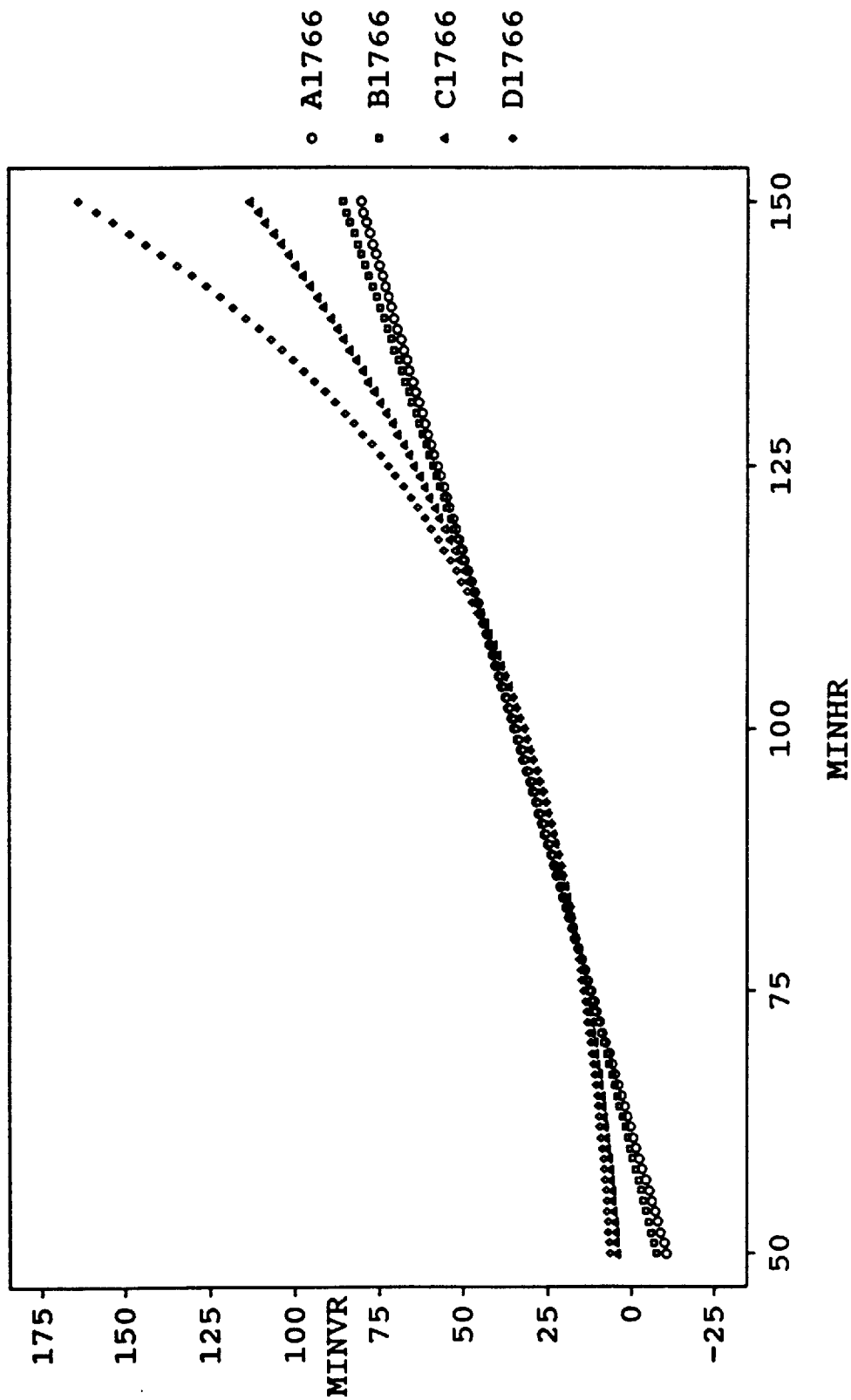


Figure 2-2. Calibration curves relating minute ventilation rate (MINVR) to minute heart rate (MINHR) developed for Subject No. 1766 through the use of Models A, B, C, and D.

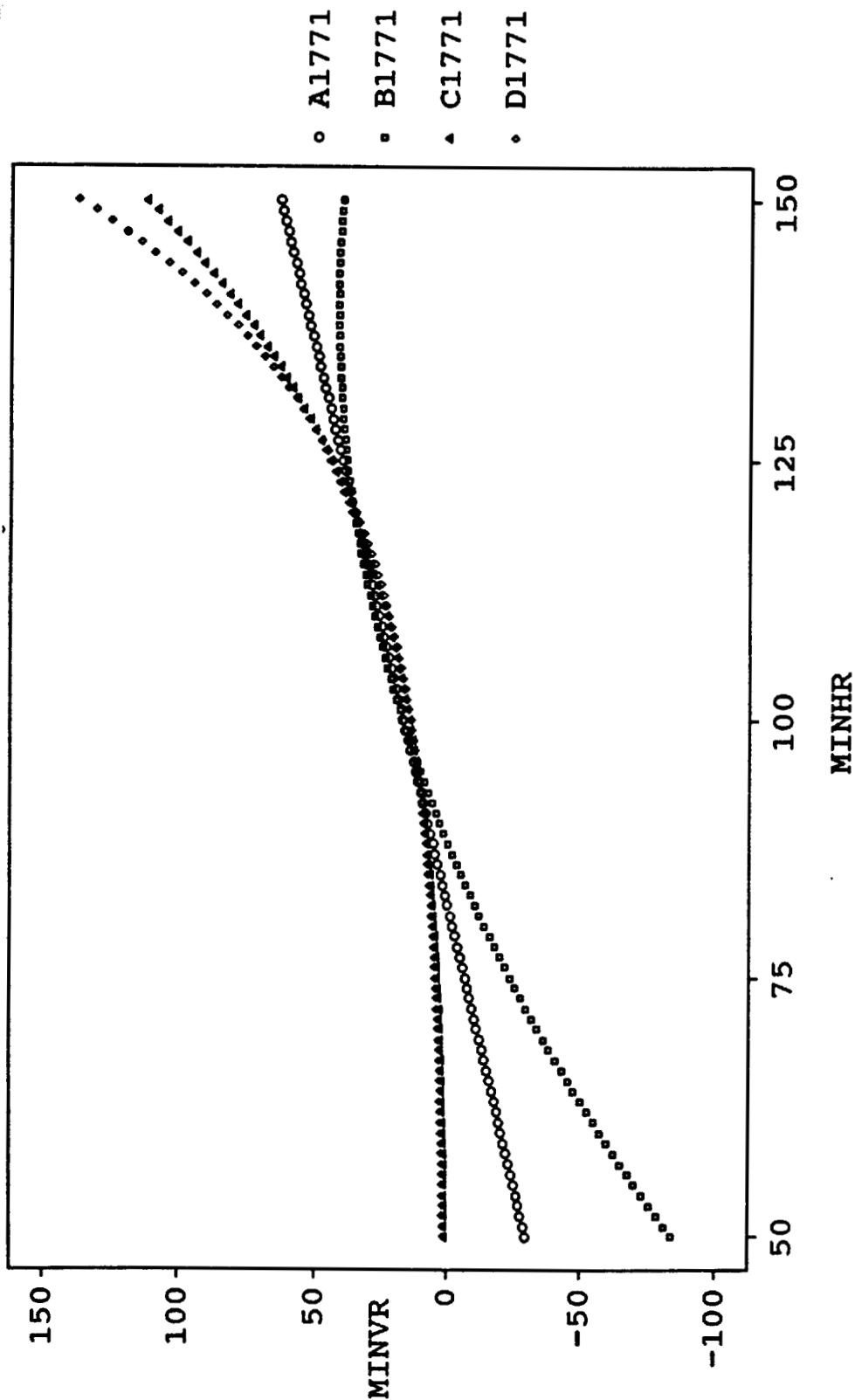


Figure 2-3. Calibration curves relating minute ventilation rate (MINVR) to minute heart rate (MINHR) developed for Subject No. 1771 through the use of Models A, B, C, and D.

Table 2-4 in this report presents the results of these calculations.

To evaluate the reasonableness of each model, researchers used the following procedure to estimate MINVR at MAP for each subject.

1. Note the value of MINHR at MAP determined by Step 2 above.
2. Insert the MINHR value in the calibration equation (A, B, C, or D) and calculate MINVR at MAP.

The resulting estimates are listed in Table 2-4 under the column heading "model-derived MINVR."

When the theoretical estimates of MINVR at MAP are compared to the model-derived estimates of MINVR at MAP, Model B produces the best matchups for Subject 1779 (the good fit example) and for Subject 1766 (the average fit example). Model A produces the best matchup for Subject 1781 (the poor fit example). Model C yields impossibly high values for MINVR at MAP for Subject 1766 (234.1 liters/minute) and for Subject 1771 (291.9 liters/minute). Model D yields even higher estimates for these two subjects (608 liters/minute for Subject 1766 and 575.5 liters/minute for Subject 1771). The Model B estimate for Subject 1771 is too low (15.5 liters/minute).

Analysts also used the four models to estimate the MINVR corresponding to the highest MINHR value reported for each of the three subjects during the diary period (164 beats/minute for Subject 1779, 139 beats/minute for Subject 1766, and 142 beats/minute for Subject 1771). Table 2-4 lists these estimates by subject and model.

The three calibration data sets share a common deficiency in that the largest MINHR value measured during the calibration phase of the study is less than one or more of the MINHR values measured during the activity diary phase. Consequently,

Table 2-4. Theoretical and model-derived estimates of minute ventilation rate (MINVR) associated with three subjects of the construction worker study.

Subject ID	Age	Fit category	Theoretical values at MAP				Model	Theoretical maximum MINHR	Model-derived MINVR	Maximum measured MINHR	Model-derived MINVR
			HR	VO ₂	V _e /VO ₂	V _e					
1779	40	Good	180	3.50	33.2	116	A	180	97.2	164	84.9
							B	180	113.5	164	94.8
							C	180	122.1	164	99.5
							D	180	137.0	164	99.5
1766	31	Average	190	4.00	33.2	133	A	190	116.6	139	70.2
							B	190	133.3	139	73.4
							C	190	234.1	139	88.8
							D	190	607.9	139	114.1
1771	39	Poor	181	3.60	33.2	120	A	181	91.8	142	55.5
							B	181	15.5	142	210.8
							C	181	291.9	142	84.3
							D	181	575.5	142	94.8

the calibration curve is being applied to MINHR values beyond the range of the calibration data. In this region, exercise physiologists would expect the slope of the relationship between MINVR and MINHR to be positive and to increase as MINHR increases. Models C and D are consistent with this expectation, as the slope of each curve increases as MINHR increases. However, these two models produce impossibly high MINVR estimates at MAP conditions for the three subjects listed in Table 2-4. Model B (the quadratic model) produced a negative slope between MINVR and MINHR for Subject 1771 in the region above the calibration range. Model A (the linear model) has a constant slope at all values of MINHR.

Models B and D perform too poorly to merit further consideration. Of the two remaining models, Model A underestimates MINVR at MAP and Model C overestimates MINVR at MAP. The unknown "correct" relationship is likely to be a monotonically increasing function that lies between these two models. Rather than attempt to guess this function, analysts applied Models A and C independently to the construction worker data to produce two separate EVR data sets. The EVR values derived using Model A are considered to represent lower bound estimates. The EVR values derived using Model C represent upper bound estimates.

THE EVENT EVR FILES

ITAQS combined the MINHR, MINVR, time/activity, and demographic data associated with each of the Hackney/Linn studies to produce a special "event EVR file" for the study. Each event EVR file lists average EVR values by event rather than by minute. In constructing each file, an event was assumed to begin whenever a subject changed activity, microenvironment, or breathing rate. An event was also assumed to begin whenever there was more than a one minute gap in the diary entries.

The EVR values listed for each subject were calculated by dividing the subject's MINVR values by the subject's estimated body surface area (BSA). BSA was estimated by the relationship

$$BSA = (0.007182)(H)^{0.725} (W)^{0.425} \quad (6)$$

where "H" is height in centimeters and "W" is weight in kilograms. This relationship was initially proposed by Dubois and Dubois¹² in 1916, confirmed by Anderson et al.,¹³ and has been used in previous analyses by ITAQS⁵ and EPA researchers.⁴

Table 2-5 lists the BSA values calculated for each of the 16 subjects of the elementary school study. It also provides subject-specific data on age, gender, race, height, and weight. In addition, Table 2-5 presents statistics by subject for the number of days monitored, the total number of events defined for the EVR file, the average number of events per day, and the average event duration. The average event duration provides a rough indicator of the level of detail available in the subject's diary, with smaller values indicating a greater level of detail. Tables 2-6, 2-7, and 2-8 present similar tabulations for the high school, outdoor worker, and construction worker studies, respectively.

Table 2-9 lists 20 variables that have been included in each of the special event EVR data sets. Data Items 6 through 12 were not available in the original data sets obtained from Dr. Linn. These items were added because (1) they were already available through a previous API task and (2) they provided additional information which assisted researchers in identifying patterns in the EVR data. All data items required special processing by ITAQS to produce a consistent data format across all four studies. This processing was performed on the NCC mainframe IBM computer using Fortran 77 programs developed specifically for this project. Appendix C provides additional information concerning each data item.

DESCRIPTIVE STATISTICS FOR EVENT EVR VALUES BY SUBJECT

Tables 2-10, 2-11, and 2-12 present descriptive statistics by subject for the event EVR values associated with the elementary school students, the high school students, and the outdoor workers, respectively. Table 2-13 presents descriptive statistics for the construction workers based on application of Model A. Model C results for the construction workers are presented in Table 2-14. Table 2-15 presents results where the Model A and Model C estimate for each event have been averaged.

The file containing elementary school data contained four event EVR values above $105 \text{ liters} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$, all associated with Subject No. 1606. As these values appear to be outliers, Table 2-10 presents descriptive statistics for this subject with and without these four values.

Subject No. 1719 of the high school student study is associated with only 15 event EVR values. Each of the other subjects of this study has at least 60 event EVR values. Table 2-11 presents group descriptive statistics for the high school students with and without Subject No. 1719.

A comparison of Tables 2-13 and 2-14 indicates that Models A and C produce similar results for the construction workers with respect to measures of central tendency (means and medians). The models, however, differ significantly with respect to estimates of minimum and maximum values. The maximums produced by the two models differ by more than 10 percent for 11 of the 19 subjects. The difference exceeds 20 percent for six subjects and 50 percent for two subjects (No. 1769 and No. 1775). Note that Model A yields unreasonably low values for some of the minimums. For example, the minimum for Subject No. 1765 is $0.30 \text{ liters} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$.

Table 2-5. Characteristics of the subjects of the elementary school study and associated data statistics.

PID	Subject characteristics					Data statistics				
	Age, years	Gender	Race ^a	Height, cm	Weight, kg	BSA ^b	Number of days monitored	Number of events	Average number of events per day	Average event duration, min
1601	11	F	3	142	28.6	1.0863	3	55	18.3	29.62
1602	11	F	3	142	30.8	1.1222	3	117	39.0	20.66
1603	11	F	3	152	36.7	1.2708	2	40	20.0	42.20
1604	11	F	3	160	71.7	1.7488	3	91	30.3	26.56
1605	11	F	3	155	39.0	1.3193	3	103	34.3	24.26
1606	11	M	3	142	29.0	1.0936	2	66	33.0	25.80
1607	11	F	4	147	44.9	1.3503	3	89	29.7	28.46
1609	10	F	4	155	26.3	1.3946	2	39	19.5	41.03
1610	10	F	1	163	54.4	1.5737	2	42	21.0	27.93
1611	11	F	2	160	48.1	1.4760	2	32	16.0	33.84
1612	12	M	2	163	51.3	1.5341	2	26	13.0	25.15
1614	12	F	3	150	53.5	1.4731	1	14	14.0	113.79
1615	12	F	3	152	42.6	1.3538	1	21	21.0	19.05
1616	12	M	3	155	39.0	1.3193	1	42	42.0	29.07
1617	12	M	2	165	44.9	1.4666	2	66	33.0	28.30
1618	12	F	3	160	49.0	1.4877	1	31	31.0	31.77

^a1: white, 2: black, 3: Asian, 4: other, 5: other.^bBody surface area, m².

Table 2-6. Characteristics of the subjects of the high school study and associated data statistics.

PID	Subject characteristics					Data statistics				
	Age, years	Gender	Race ^a	Height, cm	Weight, kg	BSA ^b	Number of days monitored	Number of events	Average number of events per day	Average event duration, min
939	16	F	1	168	51.3	1.5678	3	123	41.0	23.21
1701	17	F	1	171	61.2	1.7196	3	179	59.7	15.20
1702	14	F	4	157	50.8	1.4935	2	65	32.5	14.60
1703	15	F	2	169	68.5	1.7841	3	105	35.0	20.39
1704	17	F	1	157	56.7	1.5648	3	112	37.3	17.71
1705	17	F	3	165	57.2	1.6249	3	190	63.3	13.36
1706	14	F	4	163	58.1	1.6175	3	85	28.3	16.74
1707	16	F	2	174	73.5	1.8781	3	121	40.3	20.60
1708	16	M	1	183	75.3	1.9675	3	60	20.0	28.15
1709	15	M	1	173	100.2	2.1318	3	133	44.3	15.71
1711	17	M	3	163	52.6	1.5512	3	99	33.0	26.41
1712	14	F	1	163	70.8	1.7594	3	64	21.3	34.23
1713	14	F	4	160	44.5	1.4276	3	122	40.7	23.27
1714	15	M	1	165	64.0	1.7044	3	78	26.0	19.18
1715	15	M	1	185	66.7	1.8872	3	139	46.3	17.34
1716	15	F	3	155	49.4	1.4591	3	149	49.7	14.60
1717	14	F	3	155	47.6	1.4361	3	104	34.7	17.52
1718	16	M	1	182	62.6	1.8098	3	112	37.3	19.02
1719 ^c	13	M	3	165	49.4	1.5278	1	15	15.0	16.47

^a1: white, 2: black, 3: Asian, 4: other, 5: other.^bBody surface area, m².^cSubject reported questionable diary data.

Table 2-7. Characteristics of the subjects of the outdoor worker study and associated data statistics.

PID	Subject characteristics					Data statistics				
	Age, years	Gender	Race ^a	Height, cm	Weight, kg	BSA ^b	Number of days monitored	Number of events	Average number of events per day	Average event duration, min
124	32	M	9	180	94.3	2.1436	3	113	37.7	22.01
986	38	M	1	168	72.1	1.8137	3	110	36.7	25.66
1073	28	M	4	157	63.5	1.6421	3	92	30.7	29.45
1244	21	M	1	175	57.6	1.7025	2	69	34.5	25.74
1246	38	M	4	178	83.0	2.0093	3	173	57.7	21.16
1290	32	M	1	175	68.9	1.8376	3	128	42.7	30.67
1291	19	F	4	160	42.2	1.3961	3	100	33.3	29.73
1299	28	M	1	185	92.5	2.1692	3	178	59.3	19.66
1300	23	F	1	155	52.2	1.4927	3	122	40.7	23.04
1304	35	M	1	173	68.0	1.8080	2	46	23.0	52.17
1306	21	F	4	157	52.6	1.5159	3	70	23.3	38.57
1308	33	M	1	173	77.6	1.9116	5	121	24.2	24.23
1319	44	M	2	183	88.0	2.1022	3	52	17.3	45.89
1350	26	M	2	183	96.6	2.1874	3	120	40.0	26.93
1361	29	M	4	178	97.1	1.1475	4	128	32.0	36.10
1372	26	M	1	180	54.0	1.6907	2	72	36.0	33.99
1404	50	M	1	173	74.8	1.8828	2	94	47.0	25.03
1490	24	F	1	170	66.2	1.7683	3	141	47.0	21.45
1494	32	M	1	185	91.2	2.1556	3	114	38.0	29.35
1496	24	F	1	165	65.8	1.7248	4	147	36.8	25.10

^a1: white, 2: black, 3: Asian, 4: other, 5: other.^bBody surface area, m².

Table 2-8. Characteristics of the subjects of the construction worker study and associated data statistics.

PID	Subject characteristics					Data statistics				
	Age, years	Gender	Race ^a	Height, cm	Weight, kg	BSA ^b	Number of days monitored	Number of events	Average number of events per day	Average event duration, min
1761	26	F	1	180	81.6	2.0158	1	81	81.0	6.46
1763	29	M	3	160	61.2	1.6357	1	51	51.0	4.98
1764	32	F	2	180	74.8	1.9426	1	127	127.0	4.35
1765	30	M	1	185	65.8	1.8763	1	114	114.0	3.75
1766	31	F	4	170	77.1	1.8865	1	121	121.0	6.07
1767	34	F	1	188	99.8	2.2622	1	115	115.0	4.86
1768	32	M	2	175	70.3	1.8529	1	62	62.0	11.63
1769	32	M	1	196	104.3	2.3727	1	160	160.0	3.65
1770	26	M	1	175	81.6	1.9952	1	109	109.0	5.89
1771	39	M	1	168	68.0	1.7693	1	111	111.0	4.50
1772	32	M	1	180	117.9	2.3568	1	129	129.0	4.71
1773	39	M	1	175	77.1	1.9271	1	110	110.0	6.24
1774	23	M	4	173	68.0	1.8080	1	13	13.0	10.00
1775	42	M	1	170	68.0	1.7887	1	132	132.0	4.57
1776	29	F	4	178	81.6	1.9952	1	72	72.0	8.69
1778	35	M	4	193	99.8	2.3063	1	111	111.0	5.77
1779	40	M	1	178	79.4	1.9715	1	48	48.0	2.98
1780	37	M	4	191	109.8	2.3787	1	113	113.0	4.31
1781	38	F	4	165	74.8	1.8222	1	82	82.0	7.50

^a1: white, 2: black, 3: Asian, 4: other, 5: other.^bBody surface area, m².

Table 2-9. Data items included in event EVR files prepared by ITAQS.

Item No.	Description	Item No.	Description
1	Personal ID	11	Air Conditioner
2	Month	12	Gas Stove
3	Day	13	Season
4	Year	14	Daytype
5	Starting Time	15	Maximum Temperature
6	Demographic Group	16	Activity Classification Code
7	Gender	17	Microenvironment
8	Race	18	Breathing Rate
9	Income	19	Duration
10	Attached Garage	20	Average EVR for Event

Table 2-10. Descriptive statistics for equivalent ventilation rates averaged by event obtained from elementary school student study.

Subject identification code	Number of events	Event equivalent ventilation rate, liters·min ⁻¹ ·m ²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
1601	55	11.34	5.28	10.65	1.376	7.28	9.94	38.73
1602	117	12.82	2.48	12.61	1.194	8.79	12.20	21.22
1603	40	21.43	3.76	21.15	1.170	17.21	20.19	34.08
1604	91	9.54	3.75	9.07	1.344	5.46	8.58	30.83
1605	103	10.74	4.08	10.22	1.345	6.29	9.52	33.49
1606	66	22.76	25.63	16.54	1.972	8.39	12.78	107.76
1606 ^b	62	17.36	14.50	14.67	1.648	8.39	12.70	86.04
1607	89	18.42	3.07	18.20	1.163	14.17	17.42	28.88
1609	39	15.86	4.64	15.19	1.350	8.64	14.90	24.38
1610	42	15.04	3.49	14.65	1.260	9.34	14.23	23.55
1611	32	11.71	2.02	11.56	1.168	8.64	11.31	18.77
1612	26	6.08	1.31	5.96	1.214	4.82	5.75	9.35
1614	14	8.06	1.31	7.95	1.189	5.32	8.13	9.78
1615	21	11.67	1.03	11.62	1.093	9.89	11.69	13.56
1616	42	10.42	2.37	10.17	1.246	7.05	9.85	16.91
1617	66	6.89	2.21	6.57	1.360	3.57	6.55	13.26
1618	31	4.06	1.16	3.94	1.267	2.80	3.94	8.74
All	874	12.88	9.10	11.32	1.618	2.80	11.26	107.76
All ^b	870	12.45	6.53	11.20	1.580	2.80	11.22	86.04
All ^c	808	12.07	5.29	10.97	1.565	2.80	11.13	38.73

^aDimensionless.

^bOmits four largest values (105.31, 106.12, 106.92, and 107.77).

^cOmits Subject No. 1606.

Table 2-11. Descriptive statistics for equivalent ventilation rates averaged by event obtained from high school student study.

Subject identification code	Number of events	Event equivalent ventilation rate, liters·min ⁻¹ ·m ⁻²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
939	123	7.70	2.48	7.38	1.327	4.46	7.01	15.94
1701	179	8.47	2.81	8.11	1.325	4.69	7.79	25.01
1702	65	10.64	4.87	9.79	1.487	4.02	8.93	29.68
1703	105	9.40	4.11	8.86	1.373	5.42	8.11	38.54
1704	112	11.09	1.80	10.96	1.166	8.31	10.69	16.62
1705	190	9.67	2.68	9.39	1.261	6.15	8.92	23.39
1706	85	7.76	1.19	7.67	1.170	4.95	7.84	10.92
1707	121	8.21	3.22	7.67	1.441	3.73	7.62	18.64
1708	60	14.40	10.79	12.03	1.721	6.98	9.67	48.67
1709	133	13.18	2.59	12.94	1.211	8.44	12.67	21.16
1711	99	7.66	2.71	7.26	1.384	3.74	7.00	17.57
1712	64	8.30	2.57	7.99	1.299	5.49	7.44	17.73
1713	122	8.06	2.61	7.72	1.332	4.36	7.36	17.65
1714	78	8.92	2.29	8.67	1.264	5.75	8.51	19.60
1715	139	8.59	2.86	8.26	1.304	4.75	7.95	24.96
1716	149	6.39	1.97	6.13	1.325	3.77	6.05	14.74
1717	104	10.59	2.42	10.35	1.238	6.84	10.28	19.96
1718	112	9.82	2.96	9.44	1.316	6.02	8.84	20.87
1719	15	7.44	0.91	7.39	1.129	6.04	7.32	9.32
All	2055	9.21	3.75	8.66	1.400	3.73	8.41	48.67
All ^b	2040	9.22	3.76	8.67	1.401	3.73	8.42	48.67

^aDimensionless.

^bOmits Subject No. 1719.

Table 2-12. Descriptive statistics for equivalent ventilation rates averaged by event obtained from outdoor worker study.

Subject identification code	Number of events	Event equivalent ventilation rate, liters·min ⁻¹ ·m ⁻²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
124	113	10.30	12.29	8.02	1.745	2.25	6.99	74.67
986	110	8.73	13.42	6.85	1.649	3.75	6.26	118.51
1073	92	11.34	7.96	9.97	1.550	5.83	8.95	49.08
1244	69	13.77	6.43	12.82	1.420	7.65	11.99	44.88
1246	173	8.82	4.71	8.38	1.303	6.02	8.07	58.31
1290	128	13.04	16.23	9.12	2.055	3.96	6.55	109.65
1291	100	9.33	5.09	8.67	1.398	5.28	7.84	41.53
1299	178	18.97	21.45	13.13	2.127	5.65	9.39	119.47
1300	122	6.59	2.86	6.24	1.351	3.92	5.84	29.99
1304	46	6.10	1.58	5.92	1.273	3.60	5.85	11.72
1306	70	5.82	1.08	5.72	1.201	3.68	5.70	9.15
1308	121	12.14	6.90	11.10	1.454	7.31	9.91	45.83
1319	52	8.52	2.61	8.23	1.277	6.20	7.71	20.53
1350	120	8.90	4.09	8.33	1.395	4.57	7.67	31.91
1361	128	9.08	2.68	8.83	1.247	5.45	8.94	31.62
1372	72	5.34	1.85	5.11	1.322	3.25	4.90	16.08
1404	94	11.67	13.02	9.74	1.568	6.62	8.73	88.42
1490	141	5.09	1.02	4.99	1.214	3.14	4.87	9.12
1494	114	6.68	10.51	5.20	1.649	3.40	4.61	84.86
1496	147	9.96	5.51	9.22	1.403	5.51	8.72	40.26
All	2190	9.90	10.42	8.15	1.676	2.25	7.71	119.47

^aDimensionless.

Table 2-13. Descriptive statistics for equivalent ventilation rates averaged by event obtained from construction worker study (Model A).

Subject identification code	Number of events	Event equivalent ventilation rate, liters·min ⁻¹ ·m ⁻²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
1761	81	12.70	3.86	12.07	1.403	2.68	12.83	27.72
1763	51	15.87	5.11	15.01	1.419	6.00	15.20	30.33
1764	127	13.43	3.25	13.02	1.293	4.69	13.33	20.83
1765	114	15.92	6.64	14.42	1.696	0.30	15.32	44.04
1766	121	11.34	3.38	10.86	1.343	5.24	10.92	22.01
1767	115	10.33	3.12	9.84	1.382	3.83	10.22	21.34
1768	62	10.67	3.44	10.17	1.375	3.31	10.28	26.15
1769	160	17.35	7.14	16.02	1.493	6.17	16.13	46.35
1770	109	13.62	3.64	13.14	1.313	6.80	13.67	25.71
1771	111	15.87	7.14	12.97	2.297	0.38	16.50	28.24
1772	129	18.42	4.65	17.77	1.325	6.13	18.55	30.25
1773	110	13.92	5.52	12.84	1.514	4.27	13.09	27.22
1774	13	14.47	3.44	14.04	1.303	7.66	15.70	19.29
1775	132	18.50	8.44	15.16	2.223	0.40	19.96	36.50
1776	72	15.31	4.19	14.73	1.329	6.38	14.92	26.95
1778	111	18.04	5.35	17.29	1.344	7.40	17.29	37.94
1779	48	22.74	3.61	22.49	1.160	15.94	22.76	38.55
1780	113	12.67	2.93	12.28	1.303	5.55	12.79	20.10
1781	82	13.87	2.93	13.54	1.257	5.77	14.03	22.64
All	1861	15.00	5.89	13.74	1.587	0.30	14.17	46.35

^aDimensionless.

Table 2-14. Descriptive statistics for equivalent ventilation rates averaged by event obtained from construction worker study (Model C).

Subject identification code	Number of events	Event equivalent ventilation rate, liters·min ⁻¹ ·m ⁻²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
1761	81	12.56	4.48	11.88	1.395	4.46	12.52	34.51
1763	51	15.92	5.72	14.99	1.420	7.00	14.78	36.17
1764	127	13.82	3.09	13.48	1.253	6.69	13.50	21.34
1765	114	16.17	7.19	14.97	1.466	4.33	14.85	53.12
1766	121	10.80	2.91	10.46	1.285	6.40	10.18	22.32
1767	115	10.43	2.86	10.04	1.323	4.83	10.21	21.17
1768	62	10.96	3.09	10.61	1.280	5.49	10.45	26.20
1769	160	17.29	10.43	15.19	1.625	6.26	14.45	78.41
1770	109	14.01	3.76	13.53	1.302	7.59	13.81	28.06
1771	111	16.91	8.93	14.21	1.896	3.05	15.79	38.37
1772	129	18.36	5.17	17.63	1.340	7.52	17.91	34.78
1773	110	14.52	6.74	13.18	1.546	5.64	12.74	33.67
1774	13	14.56	3.12	14.23	1.259	8.64	15.73	19.19
1775	132	20.09	12.35	15.87	2.132	2.60	19.06	63.31
1776	72	12.97	3.13	12.61	1.267	7.34	12.45	22.64
1778	111	18.46	6.77	17.43	1.394	8.10	17.08	49.83
1779	48	22.10	4.34	21.76	1.189	15.17	22.11	43.31
1780	113	12.40	2.47	12.14	1.235	6.96	12.34	19.45
1781	82	13.47	2.88	13.17	1.244	6.64	13.43	23.27
All	1861	15.12	7.13	13.78	1.534	2.60	13.57	78.41

^aDimensionless.

Table 2-15. Descriptive statistics for equivalent ventilation rates averaged by event obtained from construction worker study (average of Models A and C).

Subject identification code	Number of events	Event equivalent ventilation rate, liters · min ⁻¹ · m ⁻²						
		Arithmetic		Geometric		Minimum	Median	Maximum
		Mean	Std. dev.	Mean	Std. dev. ^a			
1761	81	12.63	4.14	11.99	1.39	3.57	12.67	31.11
1763	51	15.90	5.40	15.01	1.42	6.50	14.86	33.25
1764	127	13.62	3.17	13.25	1.27	5.69	13.34	21.09
1765	114	16.04	6.89	14.79	1.51	2.31	15.22	48.58
1766	121	11.07	3.14	10.67	1.31	5.88	10.50	22.17
1767	115	10.38	2.99	9.95	1.35	4.33	10.23	21.25
1768	62	10.81	3.26	10.40	1.32	4.40	10.36	26.18
1769	160	17.32	8.71	15.63	1.55	6.24	15.14	62.38
1770	109	13.82	3.70	13.34	1.31	7.20	13.74	26.88
1771	111	16.39	7.98	13.80	1.96	1.71	16.30	33.30
1772	129	18.39	4.90	17.70	1.33	6.82	18.23	32.51
1773	110	14.22	6.11	13.02	1.53	4.96	12.92	30.44
1774	13	14.51	3.28	14.13	1.28	8.15	15.76	19.24
1775	132	19.30	10.28	15.68	2.11	1.50	19.62	49.91
1776	72	14.14	3.66	13.68	1.30	6.86	13.69	24.79
1778	111	18.25	6.04	17.37	1.37	7.75	17.19	43.88
1779	48	22.42	3.96	22.13	1.17	15.55	22.48	40.93
1780	113	12.54	2.70	12.22	1.27	6.26	12.57	19.77
1781	82	13.67	2.90	13.36	1.25	6.20	13.73	22.95
All	1861	15.06	6.45	13.80	1.54	1.50	13.85	62.38

^aDimensionless.

Section 3

DESCRIPTIVE STATISTICS FOR CATEGORIZED EVR VALUES

This section presents descriptive statistics for event EVR values that have been categorized according to breathing rate, activity, microenvironment, time of day, and event duration. These statistics provide an initial means for identifying factors that may be effective in predicting EVR.

BREATHING RATE CATEGORY

Four breathing rate categories were used to characterize the diary entries for each of the four studies: sleeping, slow, medium, and fast. Table 3-1 provides geometric means and standard deviations by breathing rate category for the elementary school, high school, and outdoor worker studies, respectively. Table 3-2 provides three sets of statistics for the construction worker study based on the method used to convert heart rate data to EVR data: linear (Model A), log-log (Model C), and average of linear and log-log. In each case the geometric means increase as the perceived breathing rate increases. Note that there were no EVR values characterized as "sleeping" in the construction worker study.

With respect to the construction worker geometric means, the linear and log-log values are comparable for the slow, medium, and fast categories. For example, the geometric means for the fast category are 16.3 liters · min⁻¹ · m⁻² for the linear data and 16.1 liters · min⁻¹ · m⁻² for the log-log data. The corresponding geometric mean for the averaged data is 16.2 liters · min⁻¹ · m⁻².

ACTIVITY CATEGORY

A set of 45 activity codes (numbered 1 through 45) were used to characterize the diary entries in the elementary school, high school, and outdoor worker studies.