**- DRAFT -**

# Air Conditioning Activity Effects in MOBILE6

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## 1 ABSTRACT

MOBILE6 will include revised estimates of exhaust emissions resulting from air conditioning operation. This will require air conditioning behavior and the resultant emission levels to be predicted over a wide range of ambient conditions. Test data used to develop these factors were gathered under conditions meant to represent a single extreme set of conditions. This report addresses EPA's proposed methodology for applying the "extreme" data over the broader range of ambient conditions in which air conditioner operation occurs in-use. Using air conditioning activity data collected in Phoenix, a methodology has been developed which relates temperature and humidity levels to air conditioner load using a combined measure known as the heat index. This methodology also incorporates some solar load impact and will allow adjustments for cloud cover if desired by the user. Estimates have also been developed for the fraction of vehicles equipped with air conditioning systems, and of those, the fraction of malfunctioning systems.

## 2 INTRODUCTION

The emission data to be used in the development of the MOBILE6 air conditioning factors were gathered using a test procedure intended to represent extreme ambient conditions. From these data emission factors will be developed which represent emission levels at full air conditioning load (referred to as "full-usage" emission factors). These emission factors cannot appropriately be applied to all ambient conditions, since less severe conditions will result in only partial A/C loading and hence lower emissions. The development of the full-usage emission factors will be the topic of a separate report. This report presents EPA's proposed methodology for applying the full-usage emission factors across the broad range of ambient conditions for which estimates of air conditioning emissions are required. A second aspect of air conditioning activity is market penetration; namely, the fraction of vehicles equipped with air conditioning systems, and of those, the fraction of malfunctioning systems which have not undergone repair. Proposed estimates for these factors are also presented and discussed.

## 3 OVERVIEW OF PROPOSED APPROACH

The full-usage emission factors are meant to simulate emissions which will occur under the conditions specified in the new EPA air conditioning certification test procedure: 95° F, 40 % relative humidity and full solar load (850 $W/m^2$)[1]. However, MOBILE6 will need to model air conditioning emissions at less severe conditions where the majority of vehicle operation will occur. Ideally, this model would be based on emission values collected over a range of intermediate temperature, humidity and solar load levels. Unfortunately, EPA does not possess and is not aware of any publicly available emission data which allow this sort of empirical modeling. An alternative method for modeling intermediate ambient conditions is therefore required.

The method proposed for use in MOBILE6 is to link emissions directly with the operation of the vehicle's air conditioning compressor, which is propelled by the engine using a belt in a similar manner to the vehicle's alternator. The compressor is the focus rather than driver behavior because it is the direct cause of additional load on the engine and is therefore the best indicator of how A/C system operation impacts emissions. Compressor load varies and the compressor cycles on or off (i.e. is engaged or disengaged) depending on user demand and the vehicle's response to ambient conditions. As a result, it is generally not inducing full load on the engine 100% of the time the A/C is turned on under intermediate ambient conditions. With this approach driver behavior is accounted for implicitly, however; because the compressor will only engage when the A/C system is on, compressor behavior over the course of a vehicle trip is strongly driven by A/C demand from the user.

An ideal model of this sort would link ambient conditions and emissions by modeling changes in compressor load (torque) as a function of changes in ambient conditions. Unfortunately, activity data which would allow such a link does not appear to exist. Available activity data does not include a direct measure of compressor load, but only the total time the compressor was engaged over a single vehicle trip. Therefore, the methodology proposed for MOBILE6 is to develop a relationship between emission response and the percentage of time the compressor is engaged. Again, publicly available data sufficient to empirically establish this relationship does not appear to exist, requiring an estimate to be made. Since the fraction of time the compressor is engaged over a trip (compressor-on fraction) has a direct impact on the additional load experienced by engine during a trip, it is assumed that the impact of compressor engagement on overall engine load is linearly proportional (1:1). The second assumption is that changes in emission response correlate 1:1 with changes in engine load, and hence with compressor-on fraction.
With this methodology, the compressor-on fraction is equal to the factor by which the full-usage emission factor would be scaled in MOBILE6 to derive the emission factor appropriate for the ambient condition. In other words, a compressor which is engaged 100% of the time would result in the full-usage emission factor. If the compressor is engaged only 50% of the time, 50% of the full-usage emission factor would be applied. This scaling factor will be termed the

[1] 40 CFR §86-160.00

"demand factor".

The key to this approach is the assumption that the relative emission impact due to A/C correlates 1:1 with compressor-on fraction for all pollutants. It should be noted that air conditioning system experts from the automotive industry have identified several limitations with this assumption. Specifically, compressor load fluctuates significantly when the compressor is engaged, depending on a number of factors including ambient conditions, vehicle speed, vehicle cabin temperature, and A/C system setting (e.g. fan setting, recirculation vs. outside air); A/C system response to changes in all of these factors is highly vehicle-specific[2]. Using only compressor-on fraction is a rough estimation of actual compressor load since it assumes that fluctuations in relative compressor load average out over periods when the compressor in engaged. Further, the impact of compressor load on emissions is likely not linear. However, the complexity and data demands of a compressor-load based model are prohibitive in the MOBILE6 timeframe, and as mentioned no data exists to investigate emission impacts for intermediate compressor loads. Future research activity will need to address this lack of information.

## 4 DEVELOPMENT OF DEMAND FACTORS

### 4.1 Phoenix Activity Survey

The activity data used in the development of the proposed demand factors are based on an instrumented vehicle survey conducted as part of the Supplemental Federal Test Procedure (SFTP) rulemaking process on 20 vehicles over almost 1000 trips in Phoenix, Arizona from August-October 1994[3]. Data gathered for each trip included time and date, total trip time, total time the air conditioner was on, and total time the compressor was engaged. The datalogger also recorded summarized trip information including trip distance, total idle time, and time spent in five mile-per-hour trip bins. Hourly weather information taken from Phoenix's Sky Harbor International Airport available through the National Climatic Data Center (NCDC) was used to estimate dry bulb temperature and relative humidity at the start of each trip.

### 4.2 Treatment of Data

The initial dataset used for this analysis contained 987 trips. It did not include the first and last trips for each vehicle if less than 0.25 miles; these cases were removed as part of an earlier analysis because they represented trips taken by the contractor during the datalogger installation and deinstallation process. For the MOBILE6 analysis, this trip file was further modified to improve the representativeness in the following manner:

a. Trips with a duration of 30 seconds or less were removed to eliminate stalls and other

[2] EPA/AAMA/AIAM meeting on MOBILE6 air conditioning issues, November 6, 1997

[3] "Study of In-Use Air Conditioner Operation in Phoenix, Arizona", Automotive Testing Laboratories, Inc. report to EPA (EPA Docket No. A-92-64 Item IV-A-1)

potential queuing-related cases.

b. Since the location of each trip was not known, it was necessary to assume that the linked weather information was appropriate in characterizing the conditions experienced by the vehicle on every trip. To reduce the chance that a trip was taken outside of the greater Phoenix area, all trips greater than 60 miles were deleted from the trip file. In addition, all trips for a given vehicle which followed a trip of more than 60 miles were also deleted, to reduce the chance that a vehicle made one long trip outside of the Phoenix area and remained outside the area for the remainder of the monitored trips. 60 miles was chosen as a cutpoint based on the estimated radius of the greater Phoenix area, the distance to higher altitude locations outside Phoenix along highway routes, and the distribution of trips below and above 60 miles in the dataset. For two of the vehicles for which trip distance data was not gathered, a trip duration cutpoint of 45 minutes was used.

c. Preliminary analysis of the trip data indicated that trips that were comprised solely of idle had radically different behavior than all other trips. As shown in Figure 1, the average compressor-on fraction for trips is much lower than trips consisting of even very high percentages of idle. MOBILE6 will predominantly need to predict A/C emissions over trips consisting of non-idle driving, and inclusion of idles could skew the non-idle results. Idles were therefore dropped from the trip file for the purposes of developing the non-idle demand factor relationships.

These modifications reduced the number of trips in the dataset to 672. All subsequent analyses were performed on this dataset.

## 4.3 Temperature, Humidity and Heat Index

Temperature and humidity are the most important drivers of A/C system demand. While temperature is a widely recognized influence, the load placed on the air conditioning system by humidity can account for over half of the total load under the ambient conditions of the SFTP air conditioning test procedure[2]. It is considered important, therefore, to develop a demand factor methodology which incorporates both temperature and humidity. This was supported by several comments received following the March 1997 MOBILE6 workshop that advocated the inclusion of humidity in the MOBILE6 air conditioning component.

Analysis of the Phoenix dataset indicates a strong correlation between temperature and compressor-on fraction, as shown in Figure 2 (compressor-on time is expressed as the fraction of time the compressor is engaged over the total trip time at each temperature point). The relationship between humidity and compressor-on fraction is weak, however (Figure 3), and ANOVA results indicate that when humidity is modeled with temperature it is not a significant variable. Given the importance of humidity in overall A/C system load, this is judged to be an artifact of the limited humidity range in Phoenix. Figure 4 shows relative humidity at the start of each trip as a function of temperature (the reference lines show SFTP temperature and humidity conditions); the average relative humidity for temperatures greater than 80° F was only 28%. By contrast, historical data in Houston indicate that during the summer months (when the average daily maximum temperature is over 90° F) average relative humidity at noontime is around 60%[4]. The development of demand factors which could be applied to humidity levels like those observed in Houston would require significant extrapolation of the Phoenix data. Given the weakness of the relationship between humidity and compressor-on fraction within the boundries of the Phoenix humidity levels, extrapolation of these data is not desirable.

In an attempt to more accurately assess the relative impacts of temperature and humidity on air conditioning load, therefore, a metric known as the heat index is proposed for use in developing the demand factors. Heat index is used by the National Weather Service to quantify discomfort caused by the combined effects of temperature and relative humidity. The basis of the index is the human body's ability to maintain thermal equilibrium through perspiration, taking into account numerous factors including clothing thickness, atmospheric pressure and ambient conditions. Equations have been developed which allow heat index to be calculated using only temperature and relative humidity; these equations are proposed for use in MOBILE6 to compute heat index based on temperature and humidity values input by the user (Appendix 1) [5,6]. Heat index as a function of temperature and humidity is shown in Figure 5.

The proposed approach for addressing intermediate conditions, therefore, is to develop demand factors by modeling compressor-on fraction as a function of heat index based on user input of temperature and humidity. An attractive feature of this approach is that the air conditioning activity component of MOBILE6 would be based directly on driver discomfort, the most likely factor impelling a driver's A/C behavior and thus a strong determinant in the vehicle's emission response. As shown in Figure 6, the Phoenix data exhibits a strong correlation between compressor-on fraction and heat index (for this graph each heat index value is treated as a bin in which the compressor-on factor is calculated based on all trips at that heat index level). It should be noted, however, that using heat index instead of temperature does not necessarily provide a better predictor of compressor-on fraction for the Phoenix data, because the Phoenix results are driven almost completely by temperature. Rather, the intent of using the heat index is to introduce a more equitable balance in the effect of temperature and humidity on air conditioning load not provided by the Phoenix data. The underlying assumption of this methodology is that the temperature-driven effects seen at high temperatures in Phoenix would be replicated under lower temperature but higher humidity conditions seen elsewhere in the country. Given the stated importance of humidity on air conditioning load, this assumption is believed to be more

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[4] Gale Research Inc., *The Weather Almanac*, Sixth Edition (1992)

[5] Meisner and Graves, "Apparent Temperature", *Weatherwise*, August 1985

[6] The base humidity correction factor currently in MOBILE5 will be carried over to MOBILE6. The computation of this factor and the air conditioning demand factor will be based on the same humidity data. A default specific humidity value of 75 grains/pound (as in MOBILE5) is proposed. Users will be able to input alternate humidity levels in either specific humidity or relative humidity (see Section 6), with appropriate conversions made within MOBILE6.

reasonable than ignoring or understating the impact of humidity altogether.

## 4.4 Solar Load

The proposal for air conditioning effects in MOBILE6 presented at the October 1997 workshop did not include any accounting for solar load. Comments received subsequent to the workshop, however, expressed a strong desire for the inclusion of solar load, and automotive industry experts have indicated that it is a contributing factor. Subsequent analysis of the Phoenix data indicates that a solar load impact can be discerned, and consequently a method which accounts for solar load and cloud cover (addressed in Section 4.6) is being proposed for MOBILE6.

Since solar load or cloud cover data were not available in the NCDC dataset linked to the Phoenix survey, an empirical relationship between these factors and compressor activity could not be developed directly. As an alternative, the impacts of solar load were isolated by binning all of the trips based on time of day at the start of the trip. Four "period" bins were created: night (sunset-sunrise), morning (sunrise - 10 am), peak sun (10 am - 4 pm), and afternoon (4 pm - sunset). Sunrise and sunset times for each day in the survey as reported by the U.S. Naval Observatory[7] were used to determine appropriate trip bins. The bin definitions were determined by analyzing solar radiation data gathered as part of the National Oceanic and Atmospheric Administration's (NOAA) Surface Radiation Budget Project (SURFRAD)[8]. A regression across all trips of compressor-on fraction by heat index (weighted by trip length) was performed within each bin, with the results shown in Figure 7. Since cloud cover information was not available, it could not be considered as a variable in the analysis. Historical data from Phoenix indicates that at the time of year the survey was conducted direct radiation from the sun (i.e. little or no cloud cover) is present close to 90% of the time[9], so for the purposes of this analysis all daytime trips were assumed to be taken during periods of no cloud cover. The lines show a clear difference in compressor-on fraction between nighttime and daytime at the same heat index level, indicating the importance of solar load and meriting a separation of daytime and nighttime demand equations. In support of this conclusion, ANOVA performed on the trip file with compressor fraction as the dependent variable and heat index and period as the independents indicated that period is significant to the 0.01 level.

A second question is whether a significant difference exists between the daytime periods. Figure 7 shows that as would be expected, the peak sun curve is higher than the morning and afternoon curves above 75°, while the morning and afternoon curves are similar for the mid-range heat index levels. To investigate this issue further, ANOVA analyses of compressor-on versus heat index and period were performed for all daytime trips and again for trips taken only in the morning and afternoon periods. Period was again significant to the 0.01 level for all daytime

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[7] U.S. Naval Observatory Sunrise/Sunset Web Site (http://riemann.usno.navy.mil/aa/data/docs/rs_oneyear.html)

[8] NOAA SURFRAD Web Site (http://www.srrb.noaa.gov/surfrad/surfpage.htm)

[9] Gale Research Inc., *The Weather Almanac*, Sixth Edition (1992)

trips, but was not significant when only the morning and afternoon trips were analyzed. From this it was concluded that the peak sun period is the cause of the difference between the daytime curves and merits separate treatment.

## 4.5 Proposed Demand Equations

Three demand factor equations are therefore being proposed for MOBILE6: nighttime, morning/afternoon and peak sun. The "raw" equation for each period, as well as for all daytime trips and all trips, are shown in Table 1; again, the equations reflect a weighting of the sample by trip length. The relatively low $R^2$ values compared to the composite result shown in Figure 5 are attributable to the regression being performed over the entire trip sample. A quadratic curve form is favored over more complex forms because it provides a balance between goodness of fit and more reasonable behavior at the high and low ends of the heat index range. Still, because a smaller sample of trips occurred at the high and low ends (only 5% of trips occurred when the heat index was less than 75°) the behavior of the fitted curves at these ends tend to defy engineering judgment. In particular the morning/afternoon curve is higher than the peak curve below 75°, and the night curve is higher than the daytime curves above 100°. To rectify this, separate demand equations will by applied only in the middle of the heat index range, while the higher and lower ends will be modeled with composite equations. The "daytime combined" will be used for all daytime periods at the lower end, and all individual curves will be modeled with the "all combined" equation at the high end. The heat index values at which the composite equations and period-specific equations diverge (at the low end) or converge (at the high end) are determined based on the respective points of intersection. This progression is outlined in Table 2, with the revised equation forms for each period shown in Figure 8.

Since MOBILE6 will calculate emission factors on an hourly basis, changes in solar load throughout the course of a full day will be modeled by applying the appropriate demand equations at each hour. The night equation will be applied from sunrise to sunset, the morning/afternoon equation will apply from sunrise - 10 am and 4 pm - sunset, and the peak equation will apply from 10 am - 4 pm. The peak sun cutpoints were determined based on analysis of the NOAA data on different days throughout the summer months, which indicated that direct solar radiation levels stay relatively high from 10 am to 4 pm but tend to drop off rapidly before 10 am and after 4 pm. However, the user will be allowed to input alternate time for which peak sun demand equations are applied if desired. Default sunrise/sunset times of 6 am and 9 pm will be used in MOBILE6 to approximate a typical summer day with daylight savings time. The user will also have the option of inputting alternative sunrise/sunset times in order to alter the hours for which the morning/afternoon and nighttime demand equations are applied.

## 4.6 Cloud Cover

As mentioned in Section 4.4, the proposed daytime demand equations were developed from the Phoenix data under the assumption that all trips were taken during periods of no cloud cover (an assumption that likely serves to slightly understate solar load impact). Because of this MOBILE6 will assume as a default that a sunny day is being modeled. Comments received following the October 1997 MOBILE6 workshop advocated some accounting of cloud cover, particularly for modeling seasonal emissions. It is proposed, therefore that MOBILE6 incorporate an optional input for percent cloud cover on a daily or hourly basis. The method for handling cloud cover input will be to scale back the default daytime demand equations. Analysis of NOAA solar radiation data indicates that direct solar radiation is reduced to zero when the sun is obstructed by clouds (Figure 9). Based on these data, the nighttime demand equation is proposed to represent 100% cloud cover. For intermediate cloud cover inputs, the model will interpolate between the appropriate daytime demand equation and the nighttime demand equation. Thus, 50% cloud cover at noontime would result in a demand factor halfway between the demand calculated with the peak and nighttime equations at the appropriate heat index.

## 4.7 Other Factors Considered

While ambient conditions are the primary factors in determining A/C system demand, trip-related characteristics are also likely to influence air conditioning behavior. Four such factors investigated for this analysis were soak time prior to the vehicle trip, trip duration, average vehicle speed, and percent of idle during a trip. ANOVA was performed on compressor-on fraction with these variables, with the results shown in Table 3. A technical basis exists for considering each factor, and it is likely that the dataset implicitly contains the effects of each. However, none of these variables showed enough significance to merit individual treatment; to a large extent this is likely because the Phoenix dataset does not provide adequate resolution or sample size to discern individual effects. A discussion of each factor follows.

### 4.7.1 Soak Duration

The length of soak time prior to a daytime trip could influence A/C system demand because of the impact on cabin temperature. Vehicles parked in the sun for extended periods of time experience elevated cabin temperatures compared to short soaks. However, information on several factors which would greatly influence the impact of soak time were not available, including whether a vehicle was parked in a shady location (such as a parking garage) or whether the windows were left open during the soak. Without this sort of information a meaningful assessment of soak time is difficult; not surprisingly, the ANOVA results do not show significance for this factor. A more thorough investigation of soak time impacts would require a measure of cabin temperature and more detailed trip/soak information. It is likely however, that the solar load impacts discussed in Section 4.4 are driven in part by this effect, so the impact of differing soak times are subsumed in the solar load corrections if a representative soak distribution is assumed.

### 4.7.2 Trip Duration

Trip duration could also be expected to impact air conditioning behavior. Cabin temperature over the course of a longer trip will be reduced by the A/C system, thereby reducing the need for cooling and hence the amount of time the compressor is engaged relative to the start of the trip. Figure 10 shows a series of linear regressions for compressor-on versus trip duration over four heat index ranges. Two trends emerge from these regressions: the expected downward trend as trip duration increases, and a leveling of this slope as the heat index increases. The latter trend suggests that trip duration has a more significant impact for the intermediate heat indices where cooling needs can be met in the early stages of a trip, but for higher heat indices the cooling demand remains high throughout the trip. ANOVA results do not indicate significance, however. Since the Phoenix dataset contains a wide distribution of trip durations, these effects are assumed to be accounted for implicitly in the demand equations.

### 4.7.3 Average Speed

Average speed could have an impact on A/C system load because higher rates of air flow across the vehicle's A/C condenser will reduce the work required to cool the ambient air (although this could be offset to some degree by ambient air entering the cabin at a higher rate). Regression analysis indicating a downward trend in compressor-on as average speed increases (Figure 11). Again, this effect is more prevalent for the lower heat index levels, and drops off as the heat index increases. The ANOVA results again do not indicate significance, however. These effects are assumed to be accounted for implicitly in the demand equations since the equations are based on a distribution of average speeds.

### 4.7.4 Idle Fraction

The fraction of idle during a trip could impact overall compressor operation because A/C calibrations at idle appear to be unique, as discussed in Section 4.2. For many idle-only trips the compressor is either engaged 100% of the time or 0% of the time, with most idles in the Phoenix dataset exhibiting the latter. Not engaging the compressor at idle would presumably be used as a strategy for driveability, because the relative load place on engine by the A/C system at idle is high. As shown in Figure 1, the overall average compressor-on times for all trips with idle fractions less than 100% appear similar, indicating that the effect seen on idle-only trips doesn't carry over to idles during normal trips. The ANOVA results again do not indicate significance, but it is likely that idle fraction and average speed are higher correlated so an effect solely attributable to idle is difficult to separate out. Again, to the extent there are impacts they are assumed to be accounted for in the demand equations.

## 5 MARKET PENETRATION ESTIMATES

The second component of activity determining how many vehicles in the fleet are equipped with air conditioning systems (market penetration), and of those, how many are functional. Three steps go into the development of these estimates: determining base market penetration rates by model year, estimating A/C system malfunction rate by vehicle age, and estimating how many malfunctioning systems are not repaired. This section addresses each issue.

## 5.1 Base Rates

Base market penetration data by model year were gathered from Ward's Automotive Handbook for light-duty vehicles and light-duty trucks through the 1995 Model Year. This information was available from 1972 for cars and 1975 for trucks. Year-to-year rates are more variable in the first few years of available data, so estimates for earlier model years will be estimated by applying the 1972 and 1975 rates for cars and trucks, respectively. In the later years, the rate of increase becomes more steady. Projections beyond 1995 were developed by taking the average yearly rate of increase from the last five years of available data and applying them to each subsequent year until a predetermined cap was reached. A cap of 98% was placed on vehicles and 95% on trucks under the assumption that there will always be vehicles sold without air conditioning systems, more likely on trucks than cars. The resultant base rates are shown in Figure 12. The caps are in place by the 1999 model year, and will remain for subsequent years.

## 5.2 Malfunction Rates

Of all vehicles equipped with air conditioning, it is appropriate to assume that not all of the systems are functional, requiring an estimate of the fraction of non-functioning systems by vehicle age. Unfortunately, there appears to be little publicly available data upon which to base these estimates. One available source is the annual Consumers Reports Automobile Purchase Issue, which began reporting reader survey results on A/C system malfunctions starting in 1994. The reported results from the 1997 survey were used to develop malfunction estimates by vehicle age based on a yearly increase in absolute malfunction rate of 1.5 percent (Table 4). Starting at age nine the malfunction rate will be held constant at 12.5 percent. This is based on the assumption that the increased probability of malfunction as a vehicle ages will be offset by the increased probability a vehicle will have already undergone repair as it grows older.

The second component in developing malfunction estimates is rate of repair. In the absence of concrete data, estimates were generated based on three qualitative assumptions: a) all vehicles up to three years old (assumed to be the standard bumper-to-bumper warranty period) would receive repair; b) after three years the majority of owners would still receive repair, but this percentage would decrease as the vehicle grew older, and c) vehicles built prior to the 1993 model year (estimated as a cutpoint for which Freon was replaced with R-134a on most vehicles) would experience a lower rate of repair due to the prohibitive cost of system recharging. From these assumptions, it was estimated that 100% of R-134a systems would be repaired during the warranty period, 90% in years four through eight, 80% in years nine through 13, 70% in years 14 through 18 and 60% in years 19 and up. The non-warranty period repair rates will be reduced by a factor of 0.75 for Freon (pre-1993) systems, but only if the modeled calender year is 1995 or later; if not, the R-134a estimates will be applied (in other words, lower repair rates for Freon-equipped vehicles will not be invoked if recharging with Freon was viable during the modeled calender year ). The resultant rate of unrepaired malfunctions combine the malfunction rates from Table 4 with the rate of nonrepair in a given year. These estimates are shown in Figure 13.

For a given model year, the estimate of vehicles on the road with functional air conditioning systems (referred to as adjusted penetration rates) will combine the base market penetration estimates for that model year (from Figure 12) with the unrepaired malfunction rates in Figure 13 for the appropriate vehicle age.

Due to the large degree of uncertainty in developing malfunction and repair rate estimates, it is proposed that alternate base penetration, malfunction and/or repair rates can be input by the user. This option is proposed because all three elements could vary widely depending on location. For example, A/C systems are used more in Florida than Minnesota, and hence malfunction more frequently but are also more likely to be repaired when malfunction occurs. Locality-specific datasets could be developed through surveys conducted in I/M lanes or other means. If the user only inputted a subset of these rates, MOBILE6 defaults would be used for the others. For example, locality-specific malfunction and repair information could be input and the adjusted penetration rates would be calculated within MOBILE using the default base penetration rates.

## 6 HANDLING OF AMBIENT INPUT DATA

A significant change in MOBILE6 will be ability to model on an hour-by-hour basis, whereas MOBILE5 is geared towards providing daily estimates. As proposed MOBILE6 will still provide daily output based on a weighted hourly result, but the hour-by-hour results will also be available if desired. While this increases flexibility in modeling finer increments of time, it also requires ambient conditions for every hour of the day. If these data were input by the user, at a maximum this would mean (for inputs affecting air conditioning emission factors) hourly temperature, humidity and cloud cover as well as daily sunrise, sunset and peak sun times. At a minimum, it is proposed that MOBILE6 require only (as with MOBILE5) daily maximum and minimum temperature. From this, a temperature diurnal would be modeled to provide hourly estimates of temperature, specific humidity would be assumed constant at 75 grains/pound (with relative humidity and heat index calculated on an hourly basis from this), no cloud cover would be assumed, and the sunrise/sunset/peak sun times discussed in Section 4.5 would be applied. For humidity and cloud cover, a logical intermediate step would be to accept single daily average levels which would then be applied to each hour (specific or relative humidity could be accepted). In general, however, the handling of ambient data is still unresolved, and comments are requested on this issue to gain a better understanding of user need and data availability. Once MOBILE6 is finalized guidance will be provided for developing alternate inputs both for the ambient and market penetration data.

## 7 ACKNOWLEDGMENTS

Several individuals contributed time, effort, ideas and consultation to this report. Rob French of OMS developed and provided guidance on the Phoenix dataset and contributed to the heat index concept. John Gilmore of OMS researched the base market penetration estimates and malfunction survey information. John German of OMS provided general consultation and input. Christine Dibble of the Office of Atmospheric Programs provided information on R-134a phase-

in.  John Augustine of NOAA provided information on the SURFRAD data.  Dennis Kahlbaum of AIR, Inc. provided information on the derivation of the heat index measure.  Harold Haskew of GM and Dr. Mohunder Bhutti of Delphi-Harrison provided consultation on the theoretical aspects of air conditioner operation.

**Figure 1** - Compressor-On vs. Percent Idle

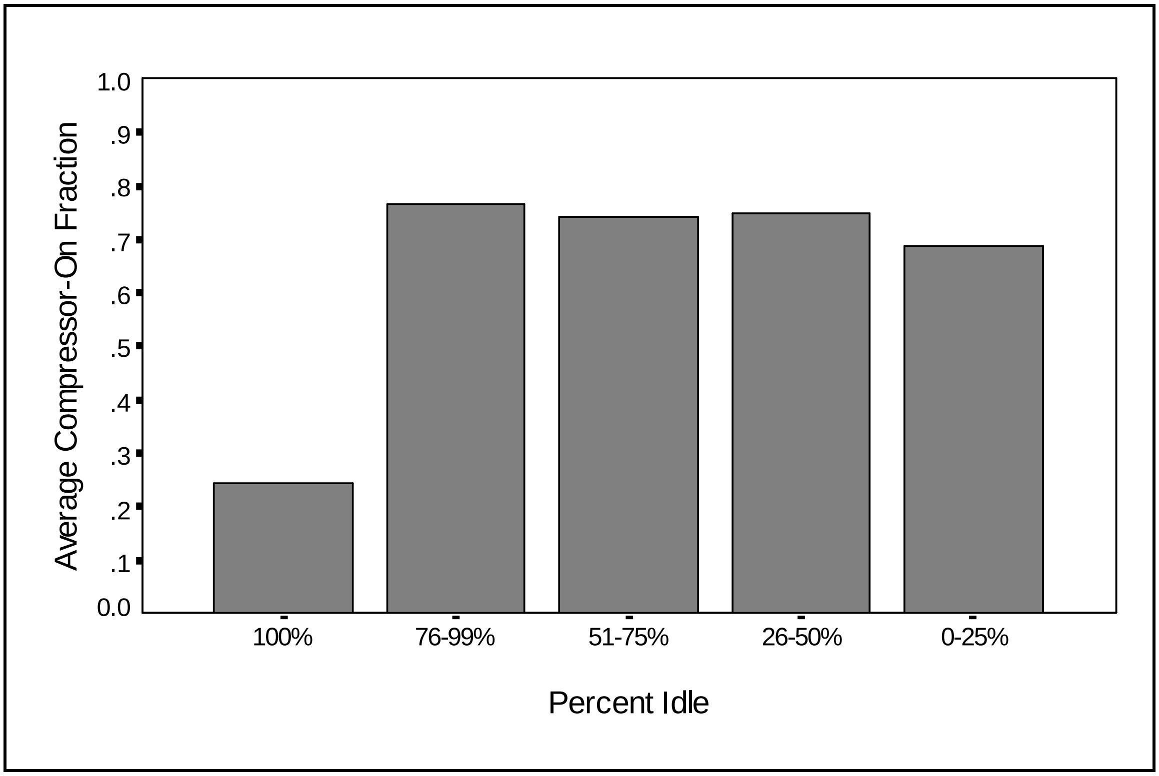



**Figure 2** - Compressor-On vs. Temperature

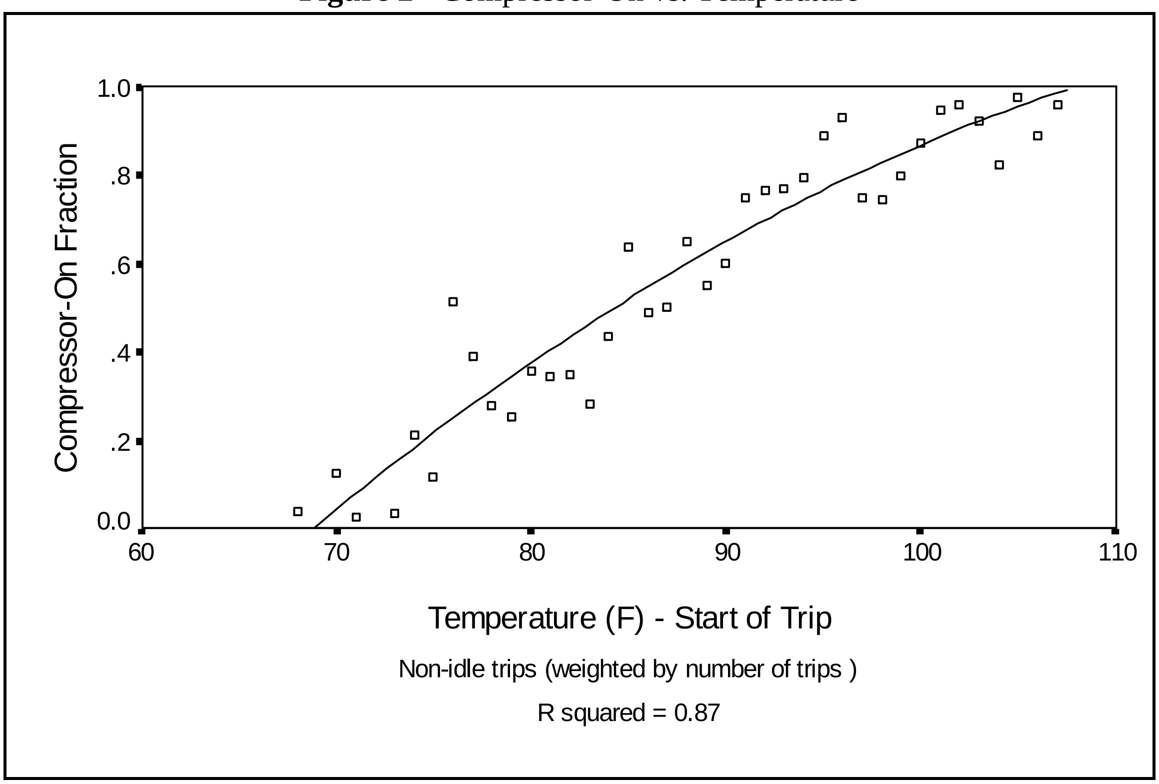


**Figure 3** - Compressor-On vs. Specific Humidity

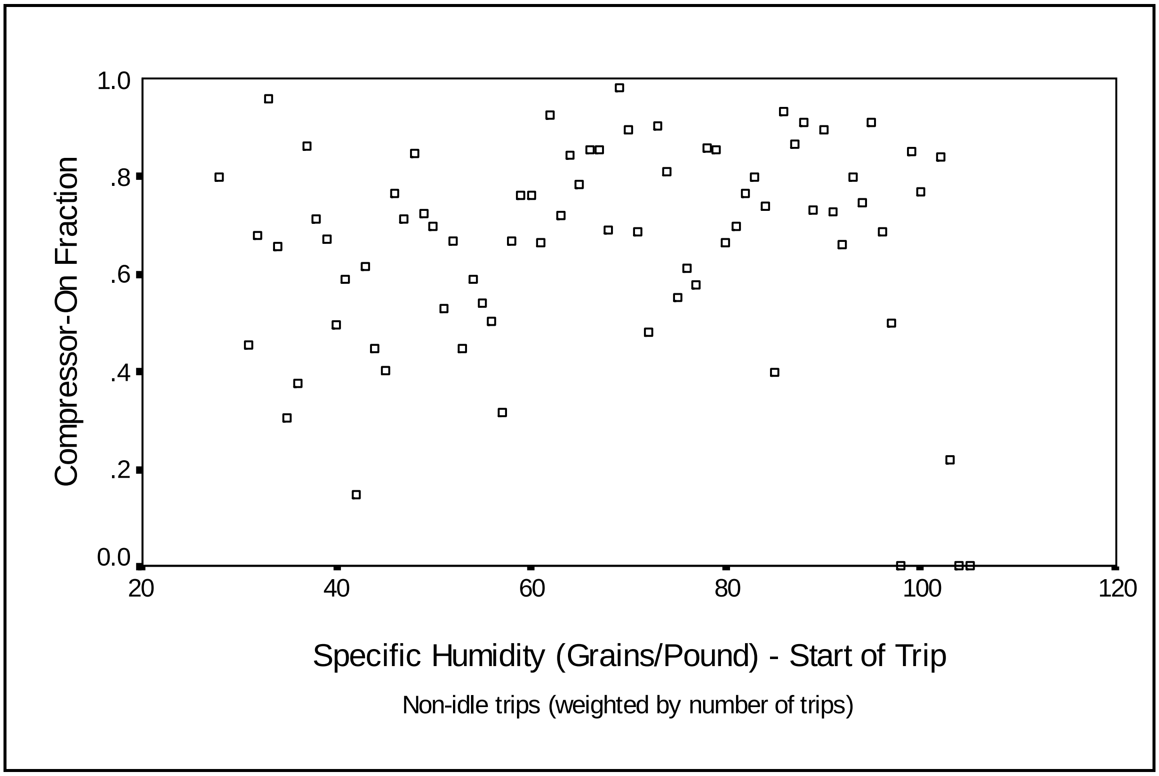



**Figure 4** - Humidity vs. Temperature for Phoenix Dataset

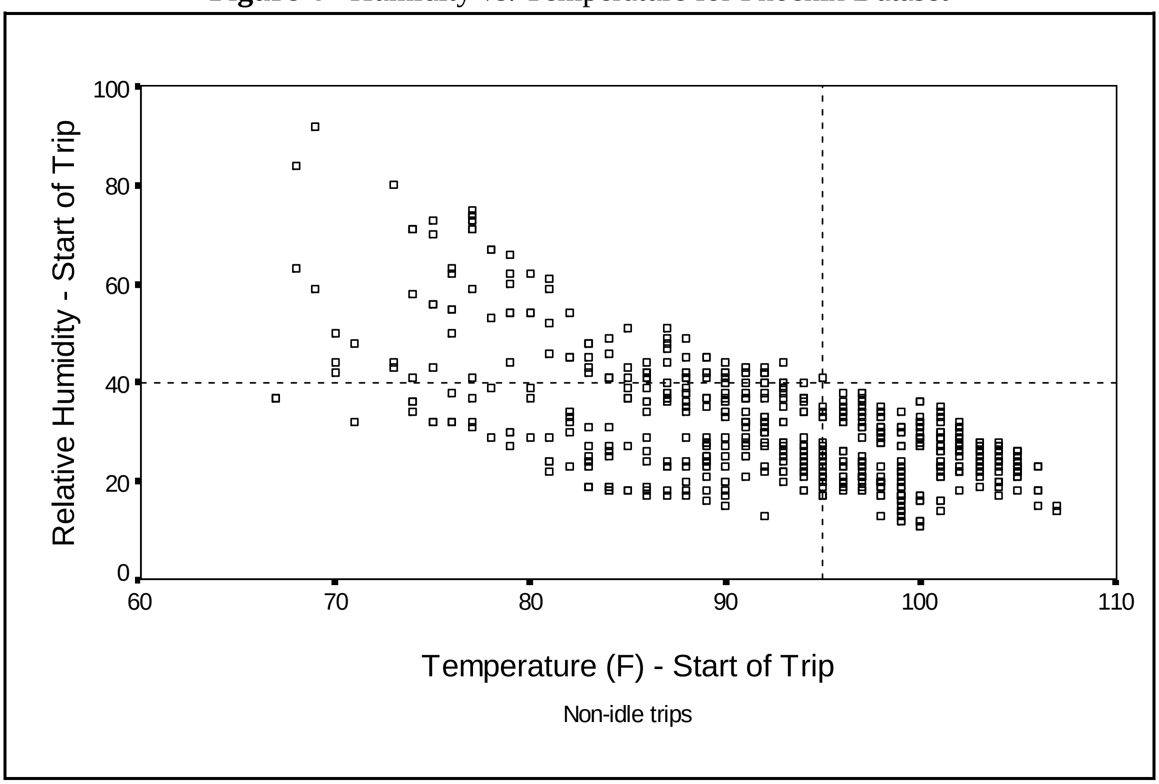


**Figure 5** - Heat Index

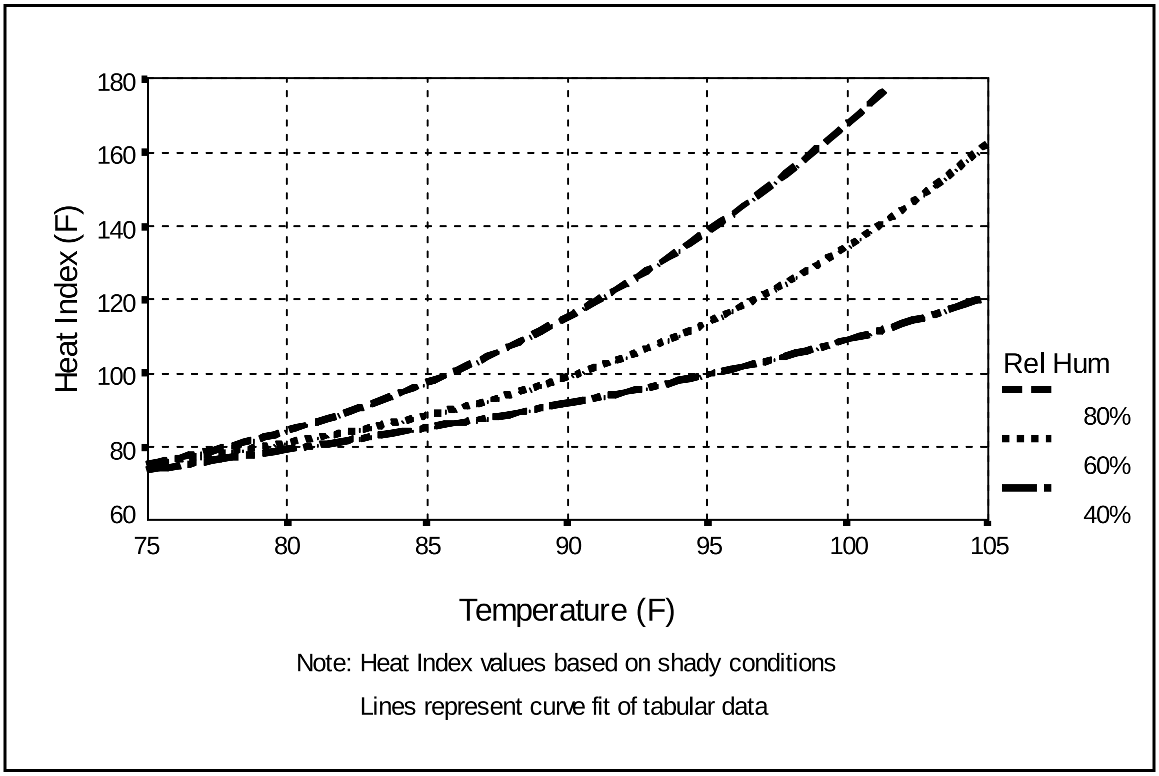



**Figure 6** - Compressor-On vs. Heat Index

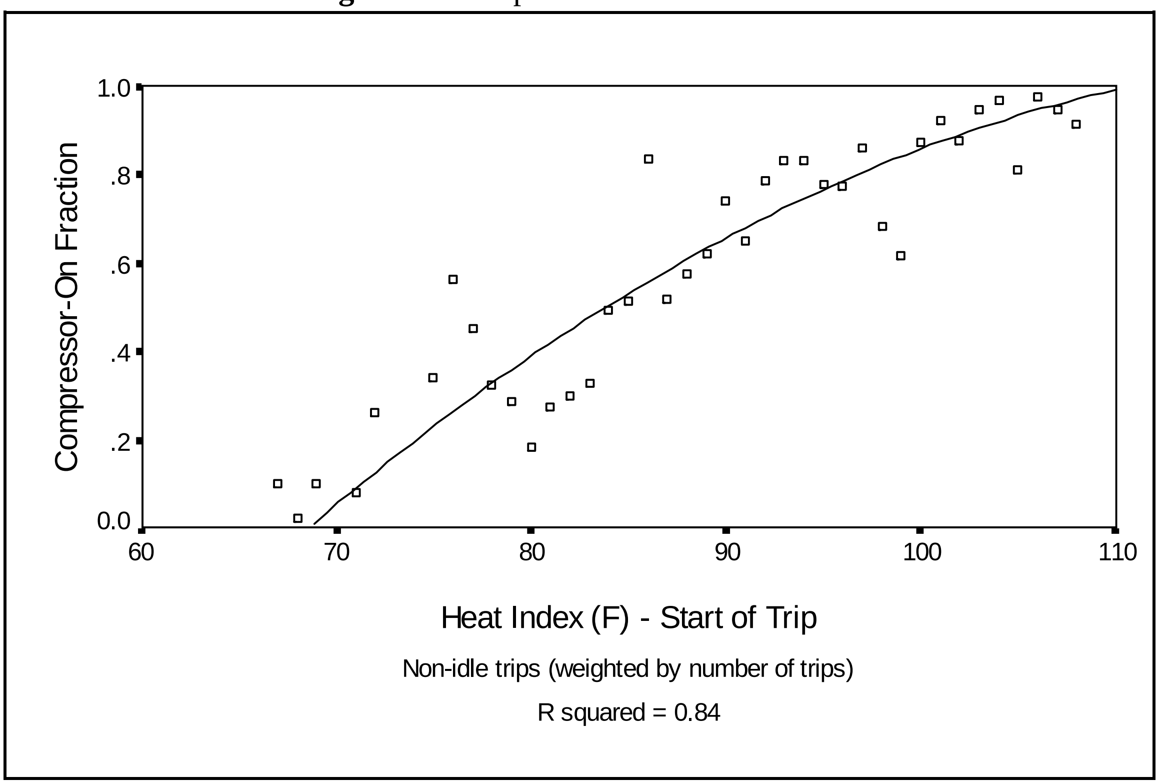


**Figure 7** - Compressor-On vs. Heat Index by Time of Day

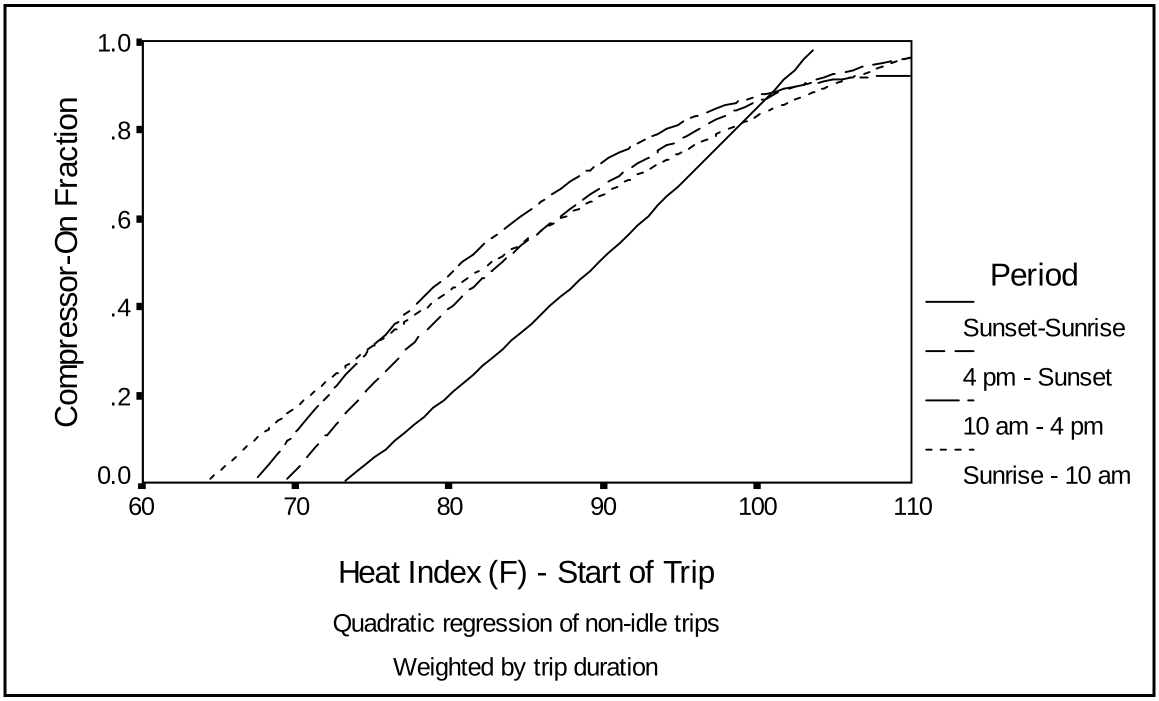



**Table 1** - Proposed "Raw" Demand Factor Equations
(Demand Factor = Constant + a*(Heat Index) + b*(Heat Index)$^2$)

| ***Period*** | ***Constant*** | ***a*** | ***b*** | ***$R^2$*** |
|---|---|---|---|---|
| **Morning/Afternoon** | -2.930273 | 0.059110 | -0.000213 | 0.54 |
| **Peak Sun** | -5.307355 | 0.113973 | -0.000521 | 0.17 |
| **Daytime Combined** | -4.101082 | 0.086382 | -0.000367 | 0.43 |
| **Night** | -1.257412 | 0.006753 | 0.000143 | 0.52 |
| **All Combined** | -3.631541 | 0.072465 | -0.000276 | 0.44 |

**Table 2** - Proposed Demand Factor Equation Forms

| *Heat Index* | *Morning/Afternoon* | *Peak Sun* | *Night* |
|---|---|---|---|
| **65 & below** | Constant = 0 | Constant = 0 | Constant = 0 |
| **66** | Daytime | Daytime | " |
| **74** | Morning/Afternoon | " | Night |
| **76** | " | Peak Sun | " |
| **96** | All | " | " |
| **101** | " | " | All |
| **104** | " | All | " |
| **110 & above** | Constant = 1 | Constant = 1 | Constant = 1 |

**Figure 8** - Proposed Demand Factor Functions

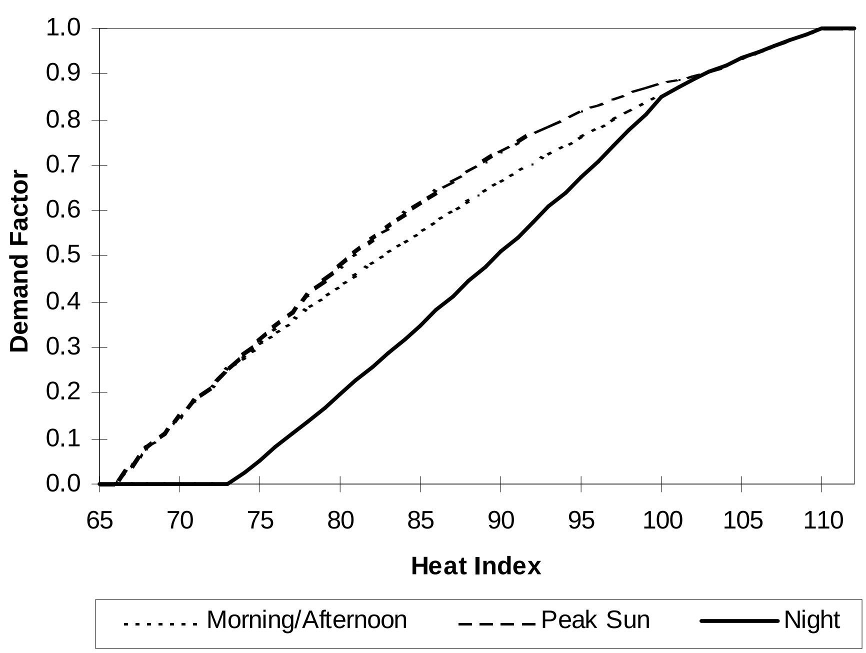


**Figure 9** - Solar Radiation - Sunny and Cloudy Day (Fort Peck, MT)

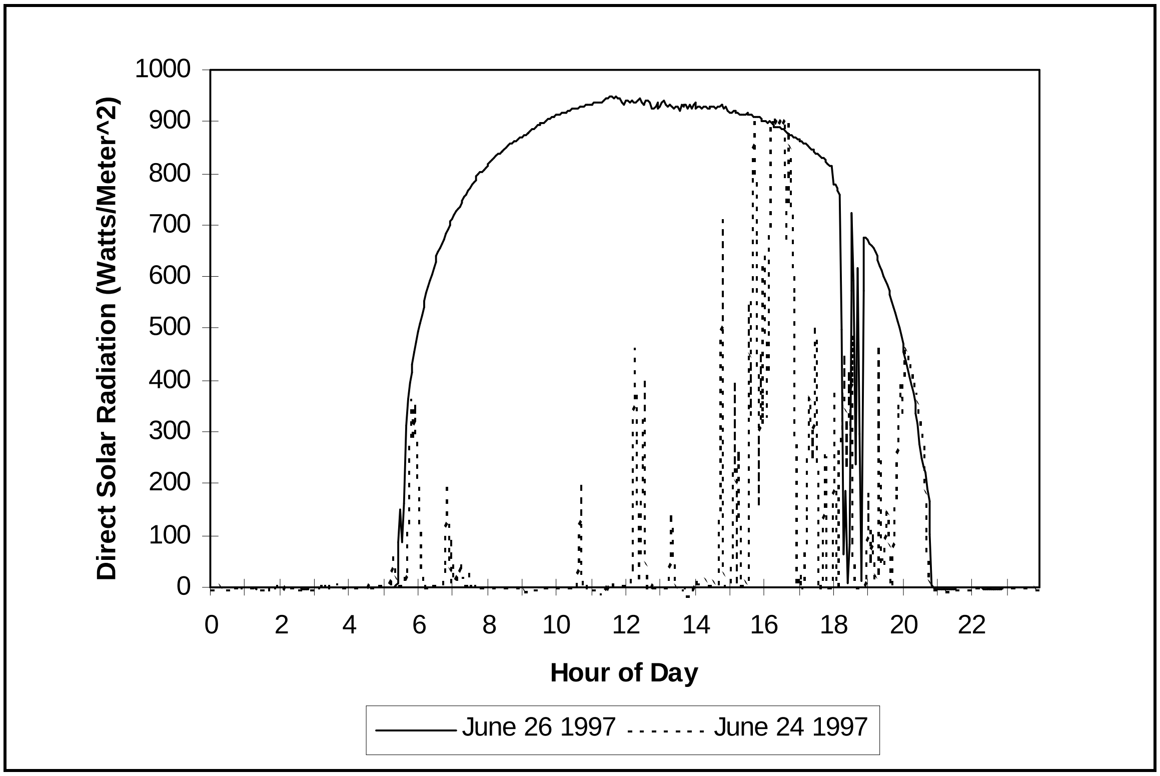



**Table 3** - Analysis of Variance (ANOVA) on Non-Idle Trip Dataset

| ***Factor*** | ***Significance*** |
|---|---|
| **Heat Index** | 0.00 |
| **Vehicle** | 0.00 |
| **Period** | 0.00 |
| **Trip Duration** | 0.25 |
| **Idle Fraction** | 0.28 |
| **Average Speed** | 0.30 |
| **Soak Duration** | 0.74 |

**Figure 10** - Compressor-On vs. Trip Duration

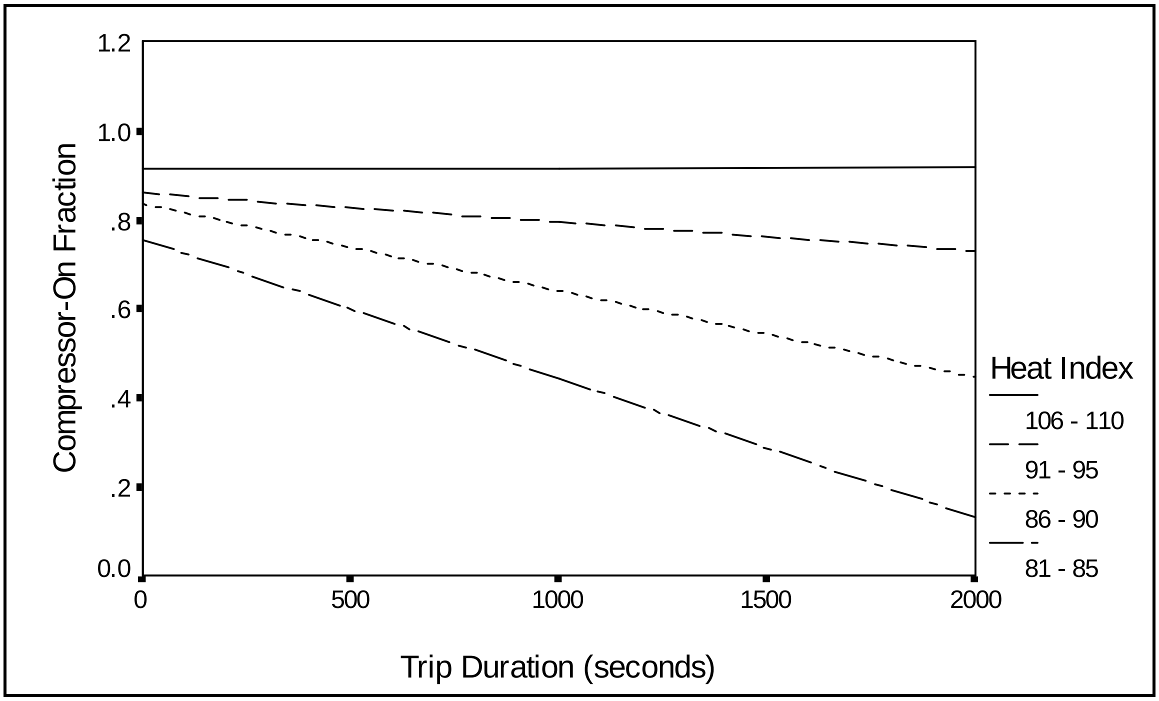



**Figure 11** - Compressor-On vs. Average Speed

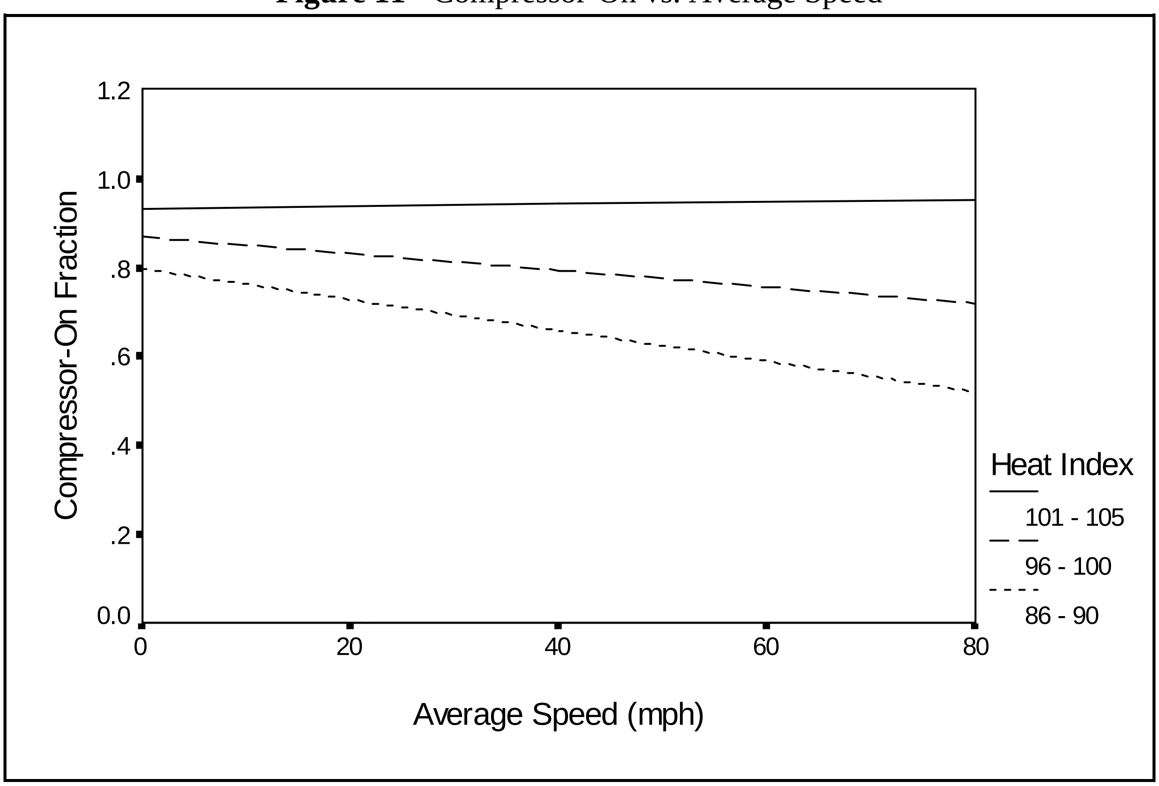


**Figure 12** - Proposed Base Market Penetration Estimates

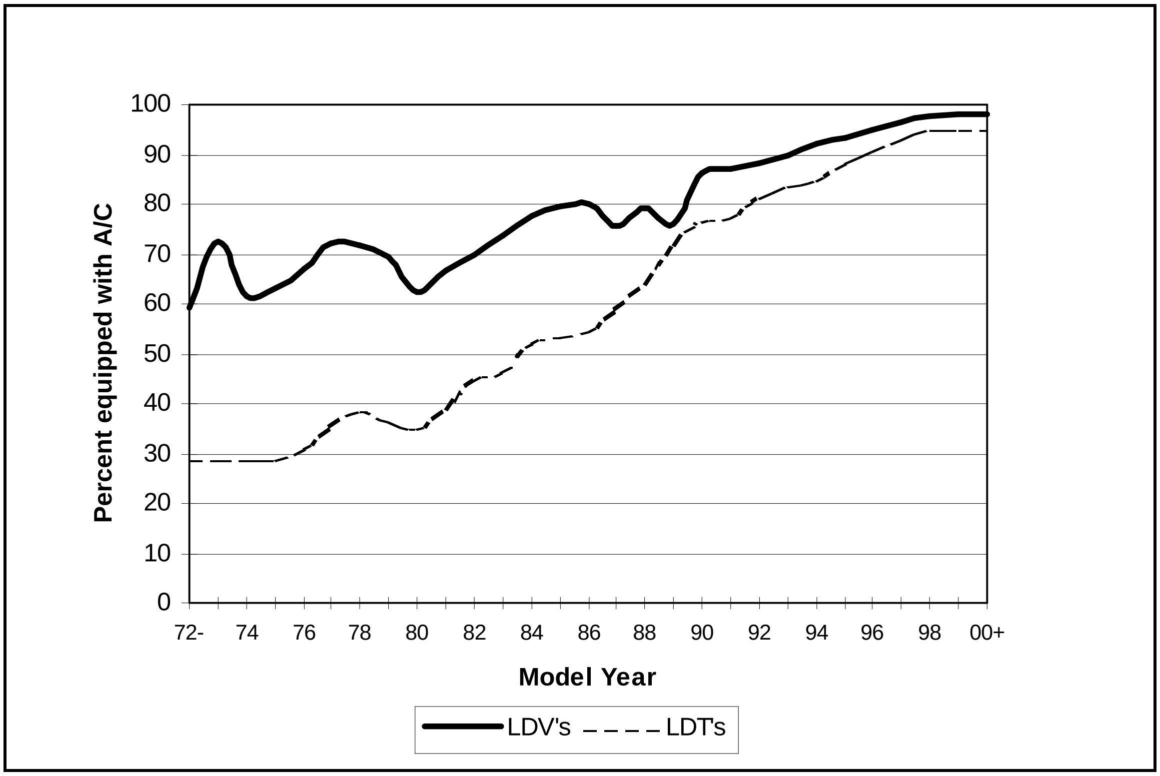
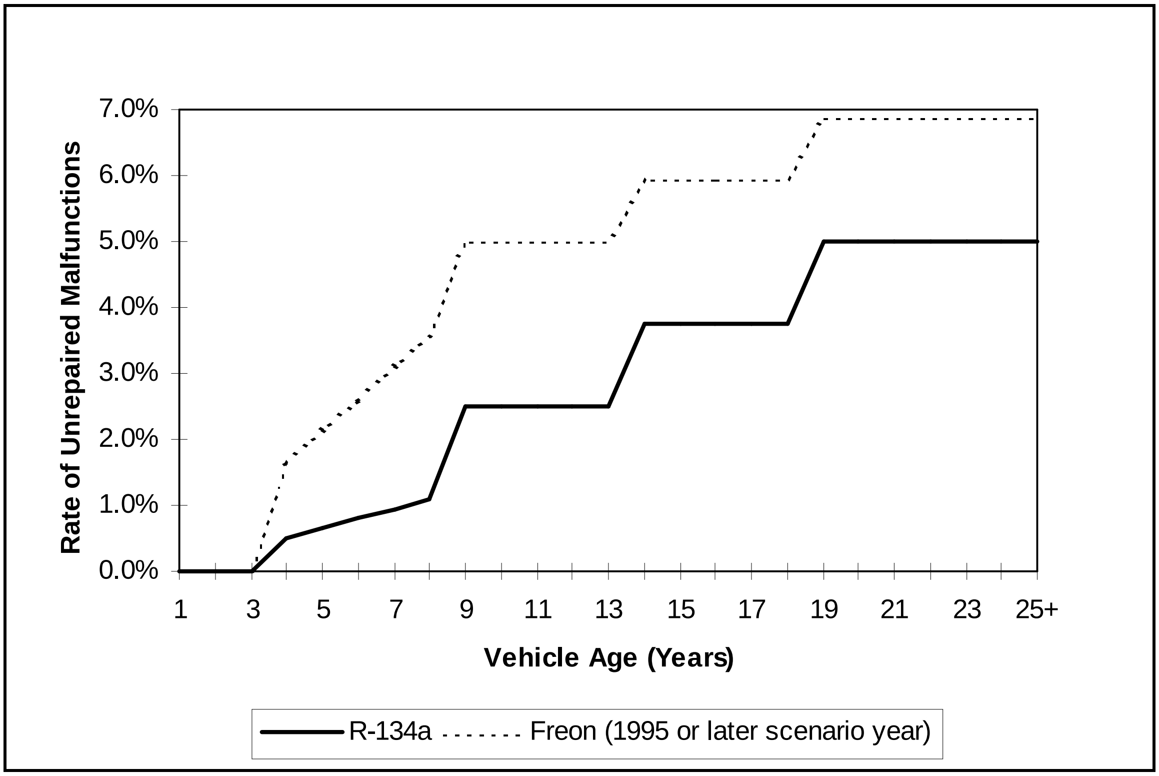



**Table 4** - Proposed Rate of A/C Malfunction

| ***Vehicle Age*** *(years)* | ***Consumers Reports**** | ***Proposed Estimates*** |
|---|---|---|
| **1** | < 2% | 0.5 % |
| **2** | 2 - 5 % | 2.0 % |
| **3** | 2 - 5 % | 3.5 % |
| **4** | 2 - 5 % | 5.0 % |
| **5** | 5 - 9.3 % | 6.5 % |
| **6** | 5 - 9.3 % | 8.0 % |
| **7** | 9.3 - 14.8 % | 9.5 % |
| **8** | 9.3 - 14.8 % | 11.0 % |
| **9-25** | n/a | 12.5 % |

* 1997 Automobile Purchase Issue

**Figure 13** - Proposed Rate of Unrepaired Malfunctions



## Appendix 1 - Heat Index Equations

Source: Meisner and Graves, "Apparent Temperature", *Weatherwise*, August 1985

This set of equations computes heat index under "mild" and "severe" sultriness. Mild sultriness indicates conditions under which thermal equilibrium can be achieved with reduced clothing thickness. Severe sultriness indicates conditions for which reductions in the skin's resistance to heat and moisture flow are required to achieve thermal equilibrium. If the required clothing thickness is less than zero for the "mild" equations, the "severe" equations are used to calculate heat index. This set of equations is based on an adult wearing trousers and a short-sleeved shirt, walking in the shade at 3.1 mph, standard sea level air pressure, wind speed of 5.6 mph and a vapor pressure of 1.6 kPa.

### Inputs: TF = Temperature (°F), RH = Relative Humidity (%)

| Variable | Equation | Comment |
|---|---|---|
| TC | (TF - 32)*(5/9) | Temperature in Celsius |
| ES | 6.11*10^ (7.567*TC)/(239.7+TC) | Saturation Vapor Pressure |
| E | 0.01*RH*ES | Relative Vapor Pressure |
| | | |
| **"Mild Sultriness":** | | |
| HER | 4.18+0.36*TC | |
| ERA | 1/(17.4+HER) | |
| QV | 180*(143-0.00112*TC-0.0168*0.1*E) | |
| EZA | 0.060606/EHC | |
| HR | 3.35+0.049*TC | |
| ARA | 1/(11.6+HR) | |
| AZA | 0.060606/CHC | |
| Q2U | ((TB-TC)+(PB-PINF)*ERA/(ZS-EZA))/(RS+ERA) | |
| QJ | (Q-QV-(1-0.84)*Q2U)/0.84 | |
| K | (.0387+ARA)+(0.0521+AZA)/0.124-((37-TC)+(5.65-0.1*E)/0.124)/QJ | |
| L | ((0.0387+ARA)*(0.0521+AZA)) - ((37-TC)*(0.0521+AZA)+(5.65-0.1*E)*ARA)/QJ)/R | |
| F | K*K-4*L | if < 0 use "Severe" |
| RF | 0.5*(-K+ SQR(F)) | |

| Variable | Equation | Comment |
|---|---|---|
| DF | 60*RF | if < 0 use “Severe” |
| W1 | 0.2016 | |
| W2 | (1-0.84)/(0.387+ERA) | |
| W3 | 0.084/(0.0387+RF+ARA) | |
| W4 | 159.0984 | |
| W5 | 37 | |
| W6 | 4.05*ERA/(0.0521+EZA) | |
| W7 | 4.05*(RF+ARA)/(0.0521+0.124*RF+AZA) | |
| **Heat Index** | (-W4+W2*(W5+W6)+ W3*(W5+W7))/(W1+W2+W3) | |
| | | |
| **“Severe Sultriness”:** | | |
| HC | 12.3 | |
| HR | 4.1+0.28*TC | |
| RA | 1/(HC+HR) | |
| ZA | 0.060606/HC | |
| QU | 180-QV | |
| ⇨ZS | ((5.65-0.1*E)*RA)/(QU*(0.0387+RA)-(37-TC))-ZA | if < 0 set equal to 0 |
| R3 | (ZS/600000)^2 | |
| C | ABS(0.0387-R3) | skips to N1 when C <= 0.0001 |
| ⇦RS | 0.5*(.0387+R3) | iterates to ZS |
| N1 | 159.0984 | |
| N2 | 37 | |
| N3 | 4.05*RA/(0.0521+ZA) | |
| N4 | RS+RA | |
| N5 | 0.2016 | |
| **Heat Index** | -N1+(N2+N3)/N4)/(N5+1/N4) | |