



# SURFACE VEHICLE STANDARD

J2766™

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(R) Life Cycle Analysis to Estimate the CO<sub>2</sub>-Equivalent Emissions  
from MAC Operation

## RATIONALE

This standard is being updated to reflect new data on the climate. It also addresses changes made to SAE J2765 to add requirements for testing of dual evaporator systems and systems with chillers. Finally, new life cycle models have been developed, so the standard is being changed to be more general.

### 1. SCOPE

This recommended best practice outlines a method for estimating CO<sub>2</sub>-equivalent emissions using life cycle analysis.

#### 1.1 History

Many companies and other organizations, including Daimler, Fiat, GM, JAMA, NREL (U.S.), Sintef (Norway), and TNO (the Netherlands), have conducted partial or complete life cycle analysis to evaluate the environmental impact of alternative refrigerant MAC systems. The life cycle analysis described here includes additional components that contribute to the CO<sub>2</sub> equivalents that are attributed to MAC systems. It is commonly referred to as life cycle climate performance (LCCP) analysis and it is being used now for analysis of emission credits in the U.S. Studies conducted by JAMA performed partial life cycle analyses which assess the total equivalent warming impact (TEWI) of alternative refrigerants. TEWI consists of two terms: (a) the direct component, which is associated with the direct release of the chemical into the atmosphere, and (b) the indirect component, which is associated with the carbon dioxide (CO<sub>2</sub>) emissions emitted during the use phase of the MAC (Mobile Air Conditioning) system. The TEWI is expressed by Equation 1.

$$\text{TEWI} = \text{GWP (Direct)} + \text{GWP (Indirect)} \quad (\text{Eq. 1})$$

**Direct emissions** result from the direct leaks of the refrigerant into the atmosphere and are an aggregate of the following emissions:

**Regular emissions**, which refer to the refrigerant leaks from the A/C system during operation

**Irregular emissions**, due to accidents, stone hits, product defects, etc.

**Service emissions**, from garages during maintenance and repair

**End-of-life emissions**, from the recovery or complete release of refrigerant at the end-of-life of the vehicle

**Leakage**, during refrigerant production and transportation.

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Thus, the direct CO<sub>2</sub> emissions are evaluated based on the GWP of each chemical and the amount of refrigerant mass emitted into the atmosphere. The direct emissions are expressed in terms of CO<sub>2</sub>-equivalent (CO<sub>2</sub>-eq.) emissions

**Indirect emissions** result from the energy consumption associated with manufacturing, use, and disposal of the MAC system, and is an aggregate of the following CO<sub>2</sub> emissions that result from:

**Manufacturing and end-of-life recycling processes** of various refrigerants

**Manufacturing and end-of-life recycling processes** of each component of the MAC system

**MAC operation**, such as those associated with the operation of the compressor and engine cooling fan, during the lifetime of the vehicle

**Fuel consumption due to MAC's mass transportation** onboard the vehicle throughout the lifetime of the vehicle

Thus, the indirect component is reported in terms of CO<sub>2</sub> emissions, considering the carbon content of the fuel utilized in each process or during vehicle operation. The JAMA and NREL studies do not include the CO<sub>2</sub> emissions associated with the end-of-life recycling processes. Furthermore, the NREL study considers only the indirect component of the TEWI. Studies conducted by GM assess the LCCP of alternative refrigerants. Such complete LCCP studies include more CO<sub>2</sub> contributions as compared to TEWI. The complete set of direct and indirect components calculated during an LCCP analysis is expressed in Equation 2:

$$\begin{aligned} \text{LCCP} = & \text{GWP (direct from leaks)} + \text{GWP [direct from additional sources: (atmospheric reaction} \\ & \text{products of refrigerant) + (manufacturing leakage) + (end-of-life refrigerant emissions)]} \\ & + \\ & \text{GWP (indirect from MAC operation) + GWP [direct from additional sources: (chemical production} \\ & \text{of refrigerant and transport) + (manufacturing MAC and vehicle assembly) + (end-of-life recycling} \\ & \text{processes)]} \end{aligned} \quad (\text{Eq. 2})$$

1.2 Assumptions and methodology for either TEWI-based or LCCP-based analyses can have a large impact on the conclusions, as it was indicated in the results presented by such studies. These updates to the SAE J-standard are the result of the SAE-IMAC-GHG-CRP efforts to improve the LCCP analysis model. The new tool is called the IMAC-GHG-LCCP tool. It reflects changes to improve the user interface and increase the operation speed as compared to the GREEN-MAC-LCCP tool. This tool uses data from the TMY3 database.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J2765 Procedure for Measuring System COP (Coefficient of Performance) of a Mobile Air Conditioning System on a Test Bench

Johnson, V., "Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach," SAE Technical Paper 2002-01-1957, 2002, <https://doi.org/10.4271/2002-01-1957>.

Papasavva, S., Monforte, R., and Hill, W., "Comparison of GREEN-MAC-LCCP© based Indirect CO<sub>2</sub>-eq. Emissions from MACs and Vehicle Measured Data," SAE Technical Paper 2010-01-1208, 2010, <https://doi.org/10.4271/2010-01-1208>.

The latest GREEN-MAC-LCCP model can be found at the SAE Interior Climate Control reference documents: <https://www.sae.org/servlets/works/postDiscussion.do?comtID=TEVBES2H&docID=&resourceID=3882418;contentType=showAll>.



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## 2.1.2 Other Publications

"Average Age of Cars and Trucks in USE 1970\_2004," found on the Oak Ridge National Lab (ORNL) website, <http://cta.ornl.gov/data/chapter3.shtml>; click at Table 3.7.

Atkinson, W. and Hoffpauir, E., MACS 2005 Survey.

Chaney, L., Thundiyil, K., Chidambaram, S., Abbi, Y. P., and Andersen, S., "Fuel Savings and Emission Reductions from Next-Generation Mobile Air Conditioning Technology in India," paper to be presented at Vehicle Thermal Management Systems (VTMS), organized by SAE and IMechE, May 2007.

Clodic, D. and Yu, Y., "Research Study on the Definition of the Implementation of a Method of Measurement of Annual Leak Flow Rates (LFRs) of MAC Systems," ACEA/ARMINES Contract, January 2006.

European Motor Vehicle Parc 2005, obtained by ACEA; published in January 2007.

Fanger, P. O., *Thermal Comfort*, Copenhagen: Danish Technical Press, 1970.

Industrial Marketing Research Auto Maintenance Survey Data, shared by ARPI (Automotive Refrigeration Product Institute).

Palandre, L., Riachi, Y., Tremoulet, A., and Clodic, D., *Intermediate Report on Practice Evaluations of Small Can Users*, December 2007.

Parsons, K., *Human Thermal Environments*, Second Edition, London & New York, Taylor & Francis, 2003; pp. 221-226.

Schwarz W., "Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old," Öko-Recherche Büro für Umweltforschung und-beratung GmbH, September 2001.

Papasavva, S., Luecken, D. J., Waterland, R. L., Taddonio, K. N., and Andersen, S. O., "Estimated 2017 Refrigerant Emissions of 2,3,3,3-tetrafluoropropene (HFC-1234yf) in the United States Resulting from Automobile Air Conditioning," Environmental Science and Technology.

U.S. Department of Energy, Buildings Technologies Program, found on the DOE internet site. Reference for the TMY2 and TMY3 is National Renewable Energy Laboratory (NREL), 1995. User's manual for TMY2s (Typical Meteorological Years), NREL/SP-463-7668, and TMY2s, Typical Meteorological Years Derived from the 1961-1990 National Solar Radiation Data Base, June 1995, CD-ROM. Golden, Colorado: National Renewable Energy Laboratory:

[http://rredc.nrel.gov/solar/pubs/tmy2/tmy2\\_index.html](http://rredc.nrel.gov/solar/pubs/tmy2/tmy2_index.html)

[https://rredc.nrel.gov/solar/old\\_data/nsrdb/1991-2005/tmy3/](https://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/)

Ward's Automotive Data:

<http://wardsauto.com/>

Global Insight Data:

<http://www.globalinsight.com/ProductsServices/ProductDetail900.htm>

Trend of Vehicle Possessions in Japan (AIRA):

<http://www.aira.or.jp>

Intergovernmental Panel on Climate Change (reference for latest global warming potential for refrigerants):

[https://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch2s2-10-2.html](https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html)

The latest report is from 2014 and can be found at this link:

[https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf)

GaBi and Boustead LCA databases:

[http://www.adm-global.org/productionsupporttools/Database\\_GaBi.html](http://www.adm-global.org/productionsupporttools/Database_GaBi.html)

[http://adm-global.org/productionsupporttools/Database\\_Boustead.html](http://adm-global.org/productionsupporttools/Database_Boustead.html)

U.S. Energy and Information Administration for CO<sub>2</sub> equivalents for different energy production methods:

<https://www.eia.gov/electricity/>

Drive cycles:

<https://www.epa.gov/emission-standards-reference-guide/all-epa-emission-standards>

<https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules>

[https://www.fueleconomy.gov/Feg/fe\\_test\\_schedules.shtml](https://www.fueleconomy.gov/Feg/fe_test_schedules.shtml)

<https://www.law.cornell.edu/cfr/text/40/1066.845>

Vehicle data:

<https://cta.ornl.gov/data/chapter3.shtml>

## 2.2 Abbreviations

### 2.2.1 Weather Databases

|          |                                                                                                       |
|----------|-------------------------------------------------------------------------------------------------------|
| City UHK | City University of Hong Kong                                                                          |
| CSWD     | Chinese Standard Weather Data                                                                         |
| CWEC     | Canadian Weather for Energy Calculations                                                              |
| ETMY     | Egyptian Typical Meteorological Year                                                                  |
| IMGW     | Instytutu Meteorologii i Gospodarki Wodnej                                                            |
| IMS      | Weather Data for Israel                                                                               |
| INETI    | Synthetic data for Portugal                                                                           |
| ISHAE    | Indian Weather Data from the Indian Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| ITMY     | Iranian Typical Meteorological Year                                                                   |
| IWEC     | International Weather for Energy Calculations                                                         |
| KISR     | Kuwait Weather Data from Kuwait Institute of Scientific Research                                      |
| SWERA    | Solar and Wind Energy Resource Assessment                                                             |

### 3. LCCP INPUT DATA

The direct and indirect CO<sub>2</sub>-equivalent emissions of each LCCP term are estimated using input data entered in the LCCP model. Some of the input data are variable and subject to specific engineering properties of each refrigerant and its interaction with the MAC system/components, such as COP (coefficient of performance), capacity, etc. Other input data may be fixed into the model. Table 1 shows possible input data to be entered by the user in the model. The following sections provide in greater detail the variable and fixed data of the models that result in a complete LCCP model for assessing the CO<sub>2</sub>-equivalent emissions of each MAC system.

**Table 1 - Input data required to be introduced by the user into the model**

| Input Worksheet Name in LCCP Model | Recommended Variable Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Recommended Fixed Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Refrigerant Property Data</b>   | User-defined refrigerants.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <ol style="list-style-type: none"> <li>1. Global warming potential (this is adjusted periodically by the Intergovernmental Panel on Climate Change, but should be fixed unless this group makes a change).</li> <li>2. Formyl fluoride.</li> <li>3. Carbonyl fluoride.</li> <li>4. Trifluoroacetyl fluoride.</li> <li>5. CO<sub>2</sub> equivalents for:               <ol style="list-style-type: none"> <li>a. Virgin refrigerant</li> <li>b. Recycled refrigerant</li> <li>c. Fugitive emissions from manufacture</li> <li>d. Refrigerant leakage during transport</li> <li>e. Fuel consumption during transport</li> </ol> </li> <li>6. Atmospheric reaction by-products.</li> </ol> |
| <b>Component Mass Input</b>        | <ol style="list-style-type: none"> <li>1. Energy and CO<sub>2</sub>-equivalent emissions to manufacture, recycle, and transport the refrigerant.</li> <li>2. Mass of refrigerant leakage during transportation.</li> <li>3. Material composition of each MAC component (percent rate of total mass).</li> <li>4. Global warming potential (GWP) of atmospheric reaction products.</li> <li>5. Global warming potential (GWP) for refrigerant.</li> <li>6. Average leakage rate.</li> <li>7. Refrigerant recycling during service.</li> <li>8. Mass for each MAC component, refrigerant charge mass, and lubricant mass.</li> </ol> | <ol style="list-style-type: none"> <li>1. Life cycle analysis energy and CO<sub>2</sub> emissions for manufacturing each material found per MAC component.</li> <li>2. End-of-life CO<sub>2</sub> emissions associated with recycling or disposal of each MAC component.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                      |

| Input Worksheet<br>Name in LCCP Model        | Recommended Variable Data                                                                                                                                                                                                                                                                                                                                  | Recommended Fixed Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Refrigerant Leakage Input</b>             | <ol style="list-style-type: none"> <li>1. Estimated loss before service.</li> <li>2. Percent do-it-yourself.</li> <li>3. Refrigerant loss per service for professional service.</li> <li>4. Refrigerant loss per service for DIYer service.</li> </ol>                                                                                                     | <ol style="list-style-type: none"> <li>1. Regular leak emissions.</li> <li>2. Irregular leak emissions.</li> <li>3. Number of services.</li> <li>4. Refrigerant loss from can heels for Professional service.</li> <li>5. Refrigerant loss from can heels for DIYer service.</li> <li>6. End-of-life refrigerant emissions without refrigerant capture.</li> <li>7. End-of-life refrigerant emissions with refrigerant capture.</li> <li>8. Refrigerant emissions from vehicle assembly.</li> </ol> |
| <b>Capacity and Energy Consumption Input</b> | <ol style="list-style-type: none"> <li>1. Capacity and COP/energy consumption data from bench tests .</li> <li>2. Idle conditions weighting factor.</li> <li>3. Weighting factors for evaporator conditions at T = 3 °C and T = 10 °C, evaporator outlet temperature.</li> <li>4. Data may include multiple heat exchangers, motors, and pumps.</li> </ol> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Drive-Cycle Input</b>                     | <ol style="list-style-type: none"> <li>1. Engine-to-compressor ratio.</li> <li>2. Engine rpms from vehicle drive cycle tests.</li> <li>3. Alternator efficiency.</li> <li>4. Belt efficiency.</li> <li>5. Alternator/engine ratio.</li> <li>6. Incremental engine efficiency.</li> </ol>                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Engine Cooling Fan Power</b>              | <ol style="list-style-type: none"> <li>1. Fan power at each ambient temperature included in the model at various speeds.</li> <li>2. Cooling fan motor efficiency.</li> </ol>                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Fuel Data</b>                             |                                                                                                                                                                                                                                                                                                                                                            | <ol style="list-style-type: none"> <li>1. Fuel consumption per unit mass.</li> <li>2. Fuel heating value.</li> <li>3. Fuel CO<sub>2</sub> emissions per liter fuel consumed.</li> </ol>                                                                                                                                                                                                                                                                                                             |
| <b>Blower Power</b>                          | <ol style="list-style-type: none"> <li>1. Blower fan power as a function of vehicle speed and ambient.</li> <li>2. Blower motor efficiency.</li> </ol>                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

| Input Worksheet Name in LCCP Model   | Recommended Variable Data                                                                                                                                                                                                                                                                                                                                                            | Recommended Fixed Data                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Vehicle and Transmission Type</b> | This data is for reference only as the vehicle size is reflected in the capacity data and the transmission type is reflected in the drive cycle rpm data.                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Climate Data</b>                  | <ol style="list-style-type: none"> <li>1. Driving distance per city.</li> <li>2. Driving time per city.</li> <li>3. Vehicle lifetime per city.</li> <li>4. Percent time A/C is on per each bin included in the model and per each city; manual A/C system.</li> <li>5. Percent time A/C is on per each bin included in the model and per each city; automatic A/C system.</li> </ol> | <ol style="list-style-type: none"> <li>1. Percent drive time at ambient during 6:00 AM to 12:00 AM for each city.</li> <li>2. Annual average temperature per city.</li> <li>3. Solar conditions per each city and per temperature bin included in the model.</li> <li>4. Relative humidity per each city and per temperature bin included in the model.</li> <li>5. Relative humidity correction using relative humidity data from tests and city conditions.</li> </ol> |
| <b>Global Vehicle Registrations</b>  | This data can be limited based on the weighted analysis that the model provides.                                                                                                                                                                                                                                                                                                     | <ol style="list-style-type: none"> <li>1. Vehicle scrap rate.</li> <li>2. Vehicle sales.</li> <li>3. Vehicle registrations.</li> <li>4. Percent A/C penetration per city.</li> </ol>                                                                                                                                                                                                                                                                                     |

### 3.1 Input Descriptions

#### 3.1.1 Refrigerant Type and Global Warming Impact

Refrigerant designations are assigned by ASHAE. These are described in ASHAE Standard 34 "Designation and Safety Classification of Refrigerants." The values for global warming are assessed by the Intergovernmental Panel on Climate Change. They do change periodically, so the fixed values in the model may need to be revised based on the latest assessment. A description of global warming potential can be found on the EPA website at: <https://www.epa.gov/ghgemissions/understanding-global-warming-potentials>.

The other values for losses during manufacturing and transportation were developed as part of the GREEN-MAC model and were agreed upon by a large part of the industry; it may have been accepted as the standard for these measurements, but again, these values may be revised based on industry agreement in the future.

#### 3.1.2 Component Mass and Energy of Production

The values for mass of individual components in the MAC system are determined by the user based on the system being evaluated. The CO<sub>2</sub> equivalents for manufacturing are determined based on the material content of these components, which are estimated by the user. These mass values are also used to estimate the fuel consumed by the vehicle in transporting these masses based on agreed upon estimates of fuel per unit mass; then, the fuel consumed is converted to CO<sub>2</sub> equivalents.

#### 3.1.3 Refrigerant Leak Rates

Leak rates for each city and each alternative refrigerant considered are included into the model. These are broken into the following categories:

- 3.1.3.1 Regular emissions, which are associated with refrigerant leaks from the A/C system during operation are an input into the model based on the SAE J2727 standard. The input value from SAE J2727 is based on a nominal temperature condition.
- 3.1.3.2 Actual leakage rates are a function of ambient temperature conditions for each city. The regression curve of Clodic, et. al, is one way to estimate the regular leak rates of vehicles running in each city, using the average annual temperature of each city, as shown in Figure 1.

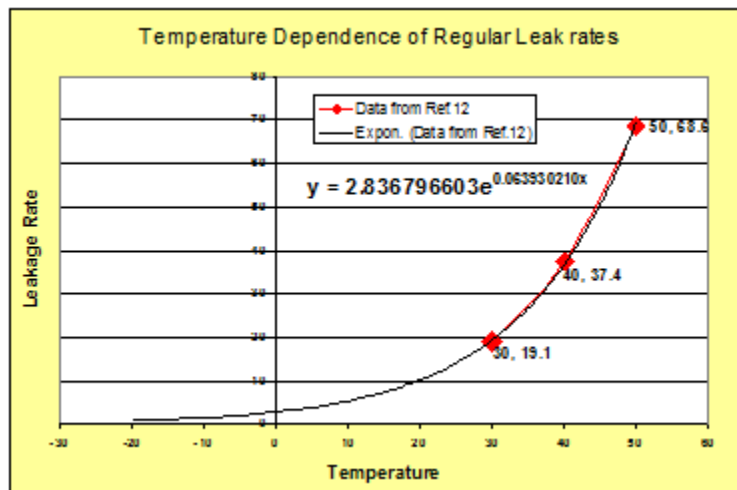


**Figure 1 - Temperature dependence of regular leak rates**

- 3.1.3.3 Irregular emissions, due to accidents, stone hits, product defects, etc., are obtained from Schwarz, et. al, and may be assumed to be the same for each city.
- 3.1.3.4 Service emissions, from garages due to maintenance and repair. The number of services per average vehicle lifetime are estimated for each city as a function of regular and irregular emissions and divided by the refrigerant loss before service. The refrigerant loss before service is a variable and can be modified by the user. A default value of 200 g may be used.
- 3.1.3.5 Service emissions are estimated for professional and do-it-yourself service and these are fixed values.
- 3.1.3.6 For professional service the emissions are estimated 35 g per service and 5 g from can heels. Professionals use 30 pound cylinders to charge 60 vehicles per cylinder. The refrigerant heel at the end of one cylinder use may be assumed to be 1.85% (~2%). Thus, the refrigerant loss due to heels per vehicle may be 5 g. These values are based on U.S. data and assumed to be the same for each city due to the lack of more data.
- 3.1.3.7 For DIYer (do-it-yourself individuals) service, the data are obtained from Palandre, et. al. The percent of DIYer service is a variable; for the U.S., the default value is 25%, as obtained from the Industrial Marketing Research Auto Maintenance Survey. For the other cities of the world, the model provides default variable values based on expert judgment and best current knowledge.
- 3.1.3.8 A weighted service leak rate is estimated from the professional and DIYer estimated values.
- 3.1.3.9 End-of-life (EOL) emissions, which are associated with refrigerant recovery or complete release at the end-of-life of the vehicle. The model considers two scenarios of EOL leakage: (a) the refrigerant is recovered, and (b) the refrigerant is completely released into the atmosphere at the end of life of the vehicle.
- 3.1.3.10 Based on data received from the Mobile Air Conditioning Society in 2007, in the U.S., 30 to 40% of vehicles have 450 g when they arrive for scrap/recycling. In these vehicles, the refrigerant is captured with 90% efficiency and 10% of the charge escapes into the atmosphere. The model estimates the regular and irregular refrigerant emissions occurred as a function of service time and estimates EOL emissions for scenarios (a) and (b). A weighted average of these two values may be obtained. Refrigerant emissions during vehicle assembly are fixed values and assumed to be the same for each city. These may be assumed to be equal to 3.5 g per vehicle.
- 3.1.3.11 Total refrigerant loss due to service may be estimated based on the service emission categories explained above.

### 3.1.4 Capacity and Energy Consumption/COP Data

- 3.1.4.1 Reference data for capacity and energy consumption/COP shall be collected as described in SAE J2765. As is explained in SAE J2765, all bench test conditions are run to simulate outside air (OSA) input to the evaporator, except for the 45 °C test condition, which simulates a re-circulated air (REC) conditions. This data could also be generated using a simulation tool, assuming this tool is validated initially to compare to bench test data.
- 3.1.4.2 This data includes data with the compressor at maximum displacement. In the input sheet, this is referred to as the 3 °C data, and then at a reduced displacement that may be used to reduce energy consumption. (Referred to as 10 °C data in the input form.)

### 3.1.5 Drive Cycle Inputs

Engine rpm data is collected for different vehicle and powertrain types second by second from the recommended drive schedule, shown in Figure 2 for different regions in the world. Each city is assigned of one of the drive cycles shown in Figure 2. Typical vehicle engine rpm are included into the model but the user has the option to enter a user-defined drive schedule. Engine to compressor rpm ratio also need to be entered. The engine rpm data is then multiplied by the compressor to engine drive ratio.