



April 28, 2020

Mr. Linc Wehrly
Compliance Division
Light-Duty Vehicle Center
Office of Transportation and Air Quality
United States Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

Mr. James Tamm
Fuel Economy Division Chief
Office of Rulemaking
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE
Washington, DC 20590

**** PUBLIC VERSION ****

RE: Off-Cycle Credit Request for Low Power Consumption Air Conditioning Compressor Clutch

Dear Mr. Wehrly and Mr. Tamm:

EPA's off-cycle program allows manufacturers to seek agency approval to use an alternative methodology to determine the CO₂ benefit of a technology that is not captured on standardized test cycles or is not available on the predetermined list of credits. The value of this technology cannot be adequately demonstrated by 5 cycle testing and it does not exist on the predetermined list of credits.

FCA submits this request for off-cycle credits from EPA in consultation with NHTSA according to 40 CFR § 86.1869-12(d) where off-cycle credits can be determined using an alternative methodology.

The attached material provides the necessary supporting detail. If you have any questions, please feel free to contact Pete Mueller at [REDACTED] [@FCAGroup.com](mailto:[REDACTED]@FCAGroup.com). Thank you for your review and consideration of this off-cycle application.

Sincerely,

A handwritten signature in black ink, appearing to read 'Gary Oshnock', is positioned above the typed name.

Gary Oshnock
Senior Manager, Regulatory Development
Vehicle Safety and Regulatory Compliance

Attachment A: Denso LE40 Air Conditioning Compressor Clutch Credit Analysis

Attachment B: FCA Vehicle List Equipped with Denso Low Power Clutch and Credit Determination

cc: David Wright

Low Power AC Compressor Clutch Technology Credit Background

FCA is requesting off-cycle greenhouse gas (“GHG”) and fuel economy credits according to the provision given in 40 CFR § 86.1869-12(d) to use an alternative methodology in demonstrating the value of the Denso low power compressor clutch technology.

Off-Cycle Alternative Methodology Determination

The Denso low power AC compressor clutch technology benefit cannot be adequately captured on existing, standardized Federal test cycles. Each of the test cycles, with the exception of the SC03 (Supplemental Federal Test Procedure with air conditioning) test, require that the air conditioning system be disabled. Demonstrating the small benefit of this technology is difficult on the SC03 test since the amount of the test benefit (signal) would be dwarfed by the amount of test error (noise). Since the Denso low power clutch cannot be meaningfully tested on a drive cycle, and it is not on the predefined menu list, an alternative methodology application has been prepared and is detailed here.

The methodology presented here relies on agency work originally presented in Section 5.2.3 of the Joint Technical Support Document (“Joint TSD”) from the “Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.” The agencies used a formula to relate the power savings of electrical devices to a credit value for the power saved. Power saved in units of Watts are then modified by duty cycle and VMT multipliers to arrive at a credit valued in grams CO₂ per mile.

Technology details and the credit calculation are presented in Attachment A-LE40 Clutch Credit Analysis.

Low Power AC Compressor Clutch Technology Description

Belt driven air conditioning compressors are powered by the engine’s accessory drive. That mechanical power from the accessory drive belt is then transmitted to the air conditioning compressor through an electromechanical clutch that can be connected/disconnected from the power source as required.

The clutch assembly is made of three individual parts:

- The armature and hub are connected to the compressor input shaft.
- The field coil is stationary and mounted on the compressor body.
- The rotor is connected to the accessory drive through a belt. The rotor and armature are separated by a small air gap.

The parts of the clutch assembly described above are shown in Figure 1 on the following page.

The field coil is a wound copper coil potted in an epoxy. When a voltage is applied to the field coil it turns into an electromagnet producing a magnetic flux. The magnetic flux draws the armature across the air gap to make contact with the rotor. Frictional contact between the rotor and the armature drive the compressor shaft.

The amount of torque that can be carried by a clutch is proportional to the amount of magnetic flux that the coil can maintain in operation. The amount of magnetic flux generated is proportional to the amount of current. The amount of torque carried by the clutch is then proportional to the power applied to the field coil. Older clutch designs required more power to maintain the torque that can now be maintained with the Denso optimized clutch design.

Denso's low power AC compressor clutch design is optimized in three ways:

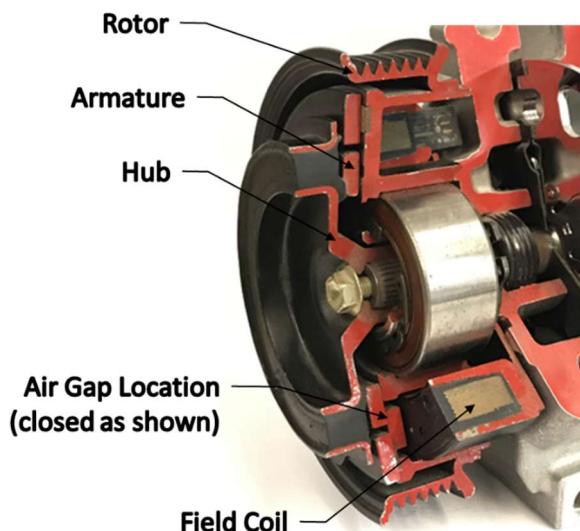


Figure 1. AC compressor clutch components showing the rotor, armature, hub and field coil.

- (1) The field coil uses smaller wire which leads to a smaller mass, a smaller coil size and an increase in coil resistance that reduces power consumption but at the expense of reduced torque transmission capability. To regain this lost capability requires the two changes below.
- (2) The shape of the field coil is modified to decrease the amount of dead space between the field coil and rotor and position it closer to the rotor. The decrease in dead space means that the field coil needs less power to transmit the same torque. The decrease in dead space is also a packaging enabler leading to less mass and a smaller size. The field coil winding process that achieves this is protected by Japanese patent 3837786.

- (3) Lastly the flux field lines are optimized by geometry changes to the rotor and armature. Flux resistance from the older design is increased at the air gap to recover the lost torque due to the changes discussed above.

The combined result of the above three design changes with the new clutch, is lower power consumption while maintain sufficient compressor torque transmission. Figure 2 shows a side-by-side comparison of the older clutch and the optimized clutch design.

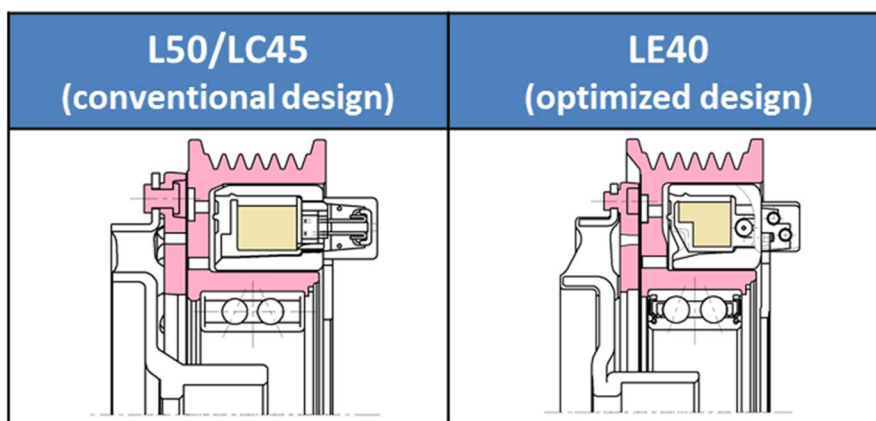


Figure 2. Side by side comparison of the old clutch design on the left and the optimized design on the right.

Low Power AC Compressor Clutch Credit Determination

The reduction in power needed from the prior generation design represented by the Denso L50/LC45 clutch lines to the new generation LE40 clutch is the basis for this credit application. As discussed above, the credit is for the electrical load reduction of the electromechanical clutch similar to the

methodology used for determining the value of solar panels and high efficiency external lighting in the Joint TSD.

Using that methodology, the power difference saved with the Denso low power clutch is 13W. Applying the formula for a 13W power savings across a duty cycle and VMT fraction of 69.1% yields 0.3 grams of CO₂ per mile due to this power savings.

A similar methodology was also employed for high efficiency alternators where the credit is proportional to the energy saved as measured by alternator VDA efficiency. Though this device is connected to an air conditioning compressor it is unaffected by the efficiency of the AC system and operates similarly to an alternator. It also does not vary with vehicle type such as passenger cars or light duty trucks as would be expected from AC efficiency credits that vary with vehicle type.

The credit asked for here is independent of the existing menu caps placed on the predetermined off-cycle list or the air conditioning efficiency menu.

Low Power AC Compressor Clutch Technology Durability

FCA requires that air conditioning compressors installed within its vehicles are designed to meet all the durability requirements of 40 CFR § 86.1869-12(d).

Conclusion

Highlights of the methodology used were described above. Additional in-depth data and analysis can be found in Attachment A. In summary, FCA believes that this methodology for determining a credit is sound and meets the requirements for granting the low power AC compressor clutch an off-cycle credit according to 40 CFR § 86.1869-12(d). FCA respectfully believes the amount of credit determined in the analysis should be granted at 0.3 grams CO₂ per mile for passenger cars and light duty trucks.

FCA has been using this clutch technology on many of its compressors in its vehicle fleet. Attachment B contains a listing of the estimated credit in megagrams affected in prior and future model years that if approved, would be modified in amended GHG/CAFE reports.

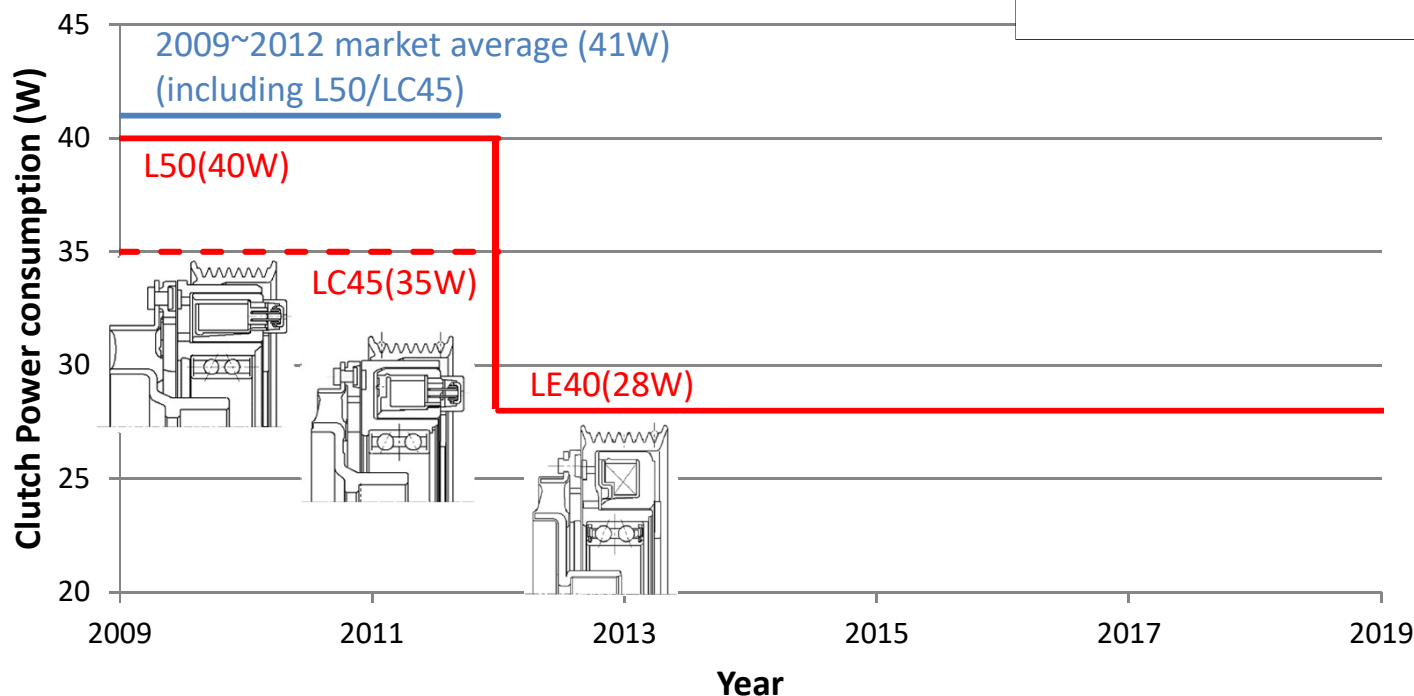
ATTACHMENT A

Denso low power consumption clutch LE40

Agenda

- Overview of market trend about clutch power consumption
- The difficulty of low power consumption clutch
- How to achieve low power consumption clutch

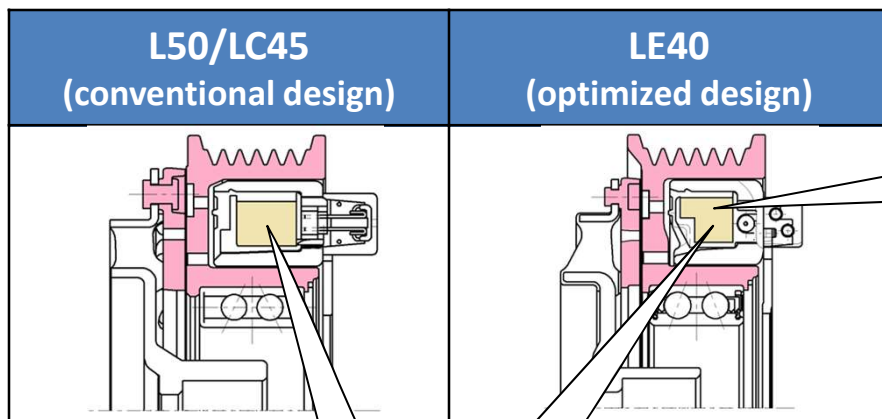
Market Trend of Clutch Power Consumption



	Supplier A	Supplier B	Supplier C	DENSO		
Clutch type	-	-	-	LC45	L50	LE40
Power Consumption (W)	40(avg.)	42(avg.)	42 (avg.)	35	40	28
Transmission Torque Capability (Nm)	55~59	35~50	52~56	41	53	41
Axial length(mm)	52~	47~	52~	47	52.5	45
Mass (kg)	2.2~	2.0~	2.1~	1.9	2.1	1.7

Power consumption of Denso's LE40 (28W) is much lower than market average (41W), while minimizing size & mass, and maintaining the necessary torque for all sizes of variable compressors.

Design Parameter	Target	Purpose
Power consumption	Reduce	Improve Fuel Economy
Size	Reduce	Improve packaging of compressor w/ clutch assembly in smaller E/G compartments.
Mass	Reduce	Improve Fuel Economy
Transmission Torque	Maintain	Maintain enough torque capability to be used on large displacement compressors (>160cc)

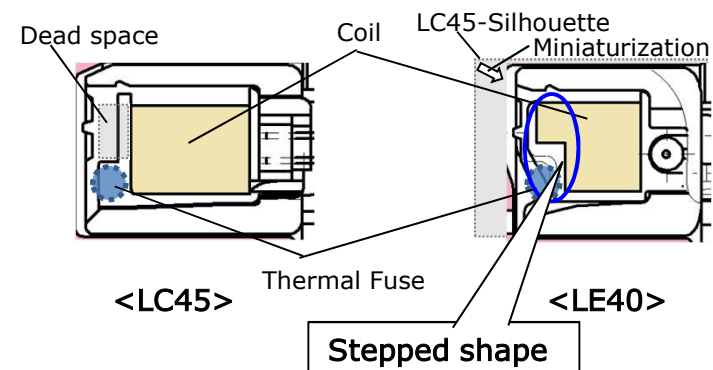


1) Reduce coil wire diameter

- + Increase Ω → **Reduce Power Consumption**
- + Reduce Coil Size
- + Reduce Coil Mass
- Reduce Ampere Turn (AT) → Reduce Transmission Torque Capability

2) Improve Coil Shape by Improved Winding

- + Reduce dead space → Reduce Coil Size and Mass



DENSO developed patented winding process to achieve a stepped coil design to reduce dead space and optimize coil size and mass.
 ✂ Patent No. 3837786

3) Improve Magnetic Circuit Design

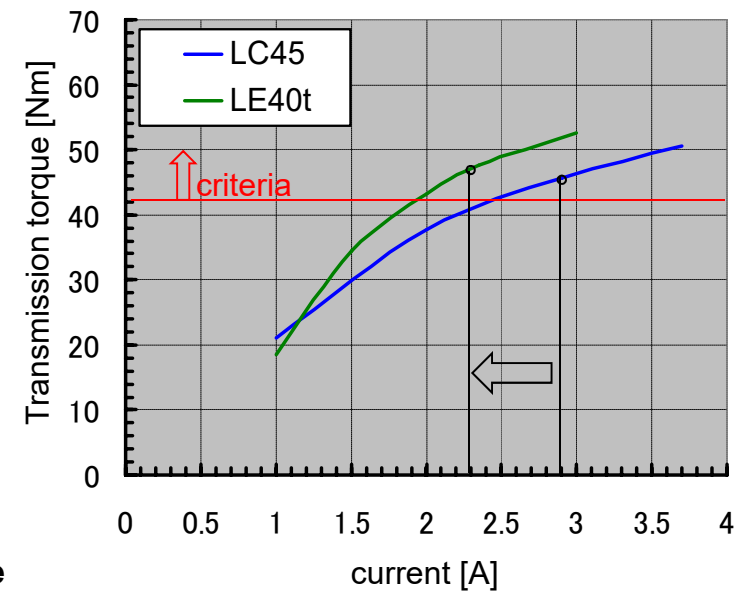
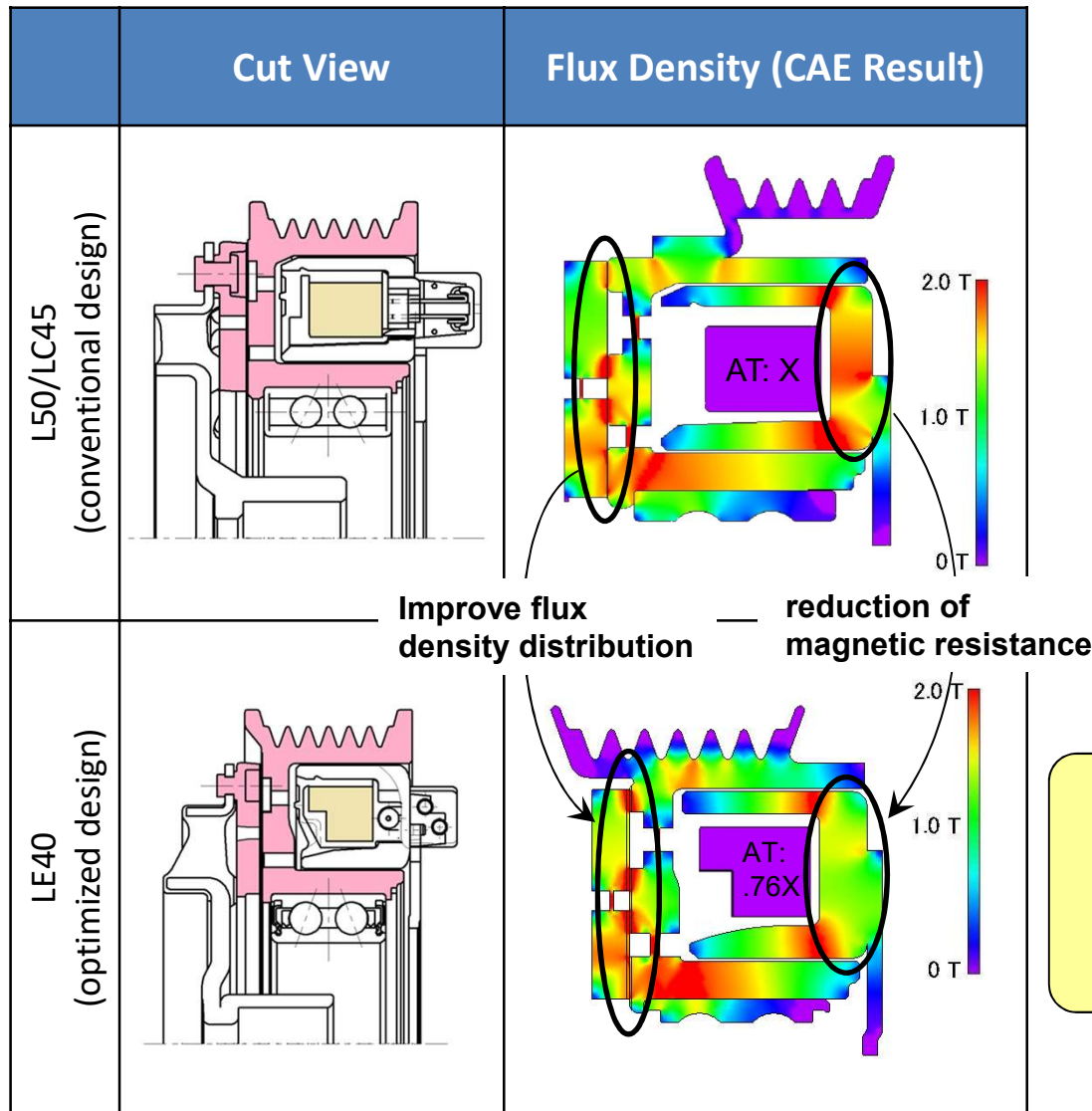
- Geometric shape changes
- Coil design allows shift in magnetic field w/more focus on contact points

+ Improve distribution of magnetic flux density →

Improve
Transmission

+ Reduce Magnetic Resistance →

Torque Capability



Through design optimization and manufacturing capabilities, DENSO is able to reduce AT, thus reducing power consumption, while maintaining the necessary torque transfer capability.

Calculation/Credit Value

Calculation method is based on The Alliance S.A.F.E. rule comment regarding Efficient Electrical Device Credit

$$Credit_{EED} = (0.032 - OnCycle_{EED}) * VMT\% \rightarrow$$

Source: <https://www.regulations.gov/document?D=NHTSA-2018-0067-12073>
Attachment 7 – New Technologies

- Credit EED = Off-Cycle Value (g CO₂/mi/W) of efficient electrical device
- OnCycle EED = On-cycle benefit (g CO₂/mi/W) of efficient electrical device = 0
- VMT% = percentage of vehicle miles travelled with technology active = 69%

$$Credit\ EED = (0.032g\ CO_2/mi/W - 0) * 69\% = 0.022g\ CO_2/mi/W$$

- Baseline clutch power consumption wattage (2012) = 41W
- LE40 clutch power consumption wattage = 28W

LE40 Credit Value

$$(41W - 28W) \times 0.022g\ CO_2/mi/W = 0.287g/mi$$

Compared with the industry standard in 2012 (when LE40 launched), LE40 offers a 13W power consumption reduction, which equates to a 0.3g/mi credit.

Supplement

Power Consumption Testing Condition:

- At 20° C ambient temperature, clutch coil resistance is measured.
- A voltage of 12V is applied to the clutch coil, and current is recorded.
- Power consumption is then calculated from current and resistance.

Supporting Equations:

$$R = \rho \times (l/A)$$

R = resistance
 ρ = electrical resistivity
l = length
A = Cross-sectional area

$$P = V^2 / R$$

P = Power
V = Voltage
R = Resistance

$$MMF = N \times I$$

MMF = Magnetomotive Force (AT)
N = Number of coil turns
I = Current (A)

Reduction in MMF = Reduction in
electromagnetic attraction force

$$W = V \times I = I^2 \times R$$

W = work (electricity consumption)
V = Voltage
I = Current
R = Resistance

US Climate Data – A/C Usage Rate Calculation (Data from LCCP Version 3b)

	United States	United States	United States	United States	United States	United States	United States	United States	United States	United States	United States
	Phoenix	Houston	Boston	Chicago	Fargo	WDC	Los Angeles	San Francisco	Sacramento	San Diego	Miami
% of Country	2.91%	13.16%	8.11%	23.97%	10.25%	13.61%	7.64%	1.52%	0.92%	2.52%	15.39%
% Manual	65%	65%	65%	65%	65%	65%	65%	65%	65%	65%	65%
<0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1-10	20%	80%	40%	40%	40%	40%	0%	60%	80%	60%	0%
11-20	38.6%	19.3%	28.6%	30.2%	24.7%	31.6%	40.9%	49.2%	49.8%	34.4%	21.2%
21-30	96.0%	93.6%	91.9%	94.8%	96.0%	93.5%	96.0%	100.0%	100.0%	97.7%	91.4%
31-40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
>40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Automatic	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
<0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1-10	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
11-20	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
21-30	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
31-40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
>40	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ambient Temperature [°C]	Phoenix	Houston	Boston	Chicago	Fargo	WDC	Los Angeles	San Francisco	Sacramento	San Diego	Miami
Average Annual Temperature (6AM-24PM)	24.30	21.14	11.03	10.70	6.50	15.70	17.42	13.97	16.67	18.31	24.99
							US A/C Usage Rate				
							69.0174				

Attachment B – FCA US LLC Credit estimates:

