TOYOTA

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April 8th 2022

Mr. Linc Wehrly
Compliance Division
Light-Duty Vehicle Center
U.S. Environmental Protection Agency
2000 Traverwood Dr.
Ann Arbor, MI 48105

Subject: Request for 2017 - 2020 MY and later Off-Cycle Credits related to application of the DENSO low power consumption compressor clutch LE40.

This correspondence represents Toyota's application for Off-Cycle credit of 0.3 grams CO_2 per mile for the use of the DENSO low power consumption compressor clutch LE40 technology for variable displacement compressors and 0.1 grams CO_2 per mile for the use of the DENSO low power consumption compressor clutch LE40 technology for fixed displacement compressors. The credit amount has been determined using the alternative methodology outlined in 40 CFR § 86.1869-12(d), details of which can be found on the following pages of this correspondence.

Per 40 CFR § 86.1869-12, vehicle manufacturers may obtain off-cycle credits for the use of a CO_2-reducing technology whose benefits are not adequately captured on the Federal Test Procedure and/or the Highway Fuel Economy Test. This application is submitted in accordance with the provisions of subsection (d), which enables manufacturers to earn credits by demonstrating that the applicable technology provides GHG reduction benefits via an alternative EPA-approved methodology.

If you have any questions regarding this matter, please contact Mr. Arvon Mitcham of my staff at (734) 995-5587 or email: arvon.mitcham@toyota.com at your earliest convenience.

Thank you very much for your consideration of Toyota's application and we would look forward to any additional dialog regarding this credit request.

Sincerely,

William Meschievitz
Group Manager
Powertrain Certification and Compliance

Attachment(s):
DENSO low power consumption compressor clutch LE40 (CBI and FOIA versions)

Request for 2017-2020 MY and later Off-Cycle Credits related to application of the DENSO low power consumption compressor clutch LE40

Overview:

Pursuant to 40 CFR 86.1869-12(d), 49 CFR 531.6(b), and 49 CFR 533.6(c) Toyota Motor Corporation (herein referred to as "Toyota") requests the following greenhouse gas off-cycle credit amount for the DENSO low power consumption compressor clutch LE40 (LE40) technology.

Technology	CO2g/mi Credit
LE40 magnet clutch variable displacement compressor	0.3
LE40 magnet clutch fixed displacement compressor	0.1

Table 1: LE40 Credit Request

This technology allows for reduced power consumption during compressor operation through improved and more efficient clutch technology. This technology is similar to other compressor efficiency technology that has been approved for off cycle credit alternative application for Denso SAS/SES compressor technology.

This compressor clutch technology was first used on the 2011MY Toyota Corolla and has since been adopted on 2016MY Toyota RAV4, 2016 Toyota Corolla and the 2020MY 4Runner.

Description of Technology

In vehicles equipped with belt driven compressors, the magnetic clutch transmits and disconnects power between the engine and the compressor during normal operation. In this operation the efficiency and design of the clutch can reduce overall power consumption. Through the use of the DENSO's LE40 magnet compressor clutch which is smaller, lighter and more energy efficient in comparison to those conventional magnet clutches, power consumption can be reduced while still meeting the usage needs of the customer.

Magnetic clutch components introduction:

Stator: Holds coil and generates magnetic force
Hub: Receives power from the rotor and transmits it to the compressor shaft
Rotor: Receives power from the engine via a belt and transmits it to the hub

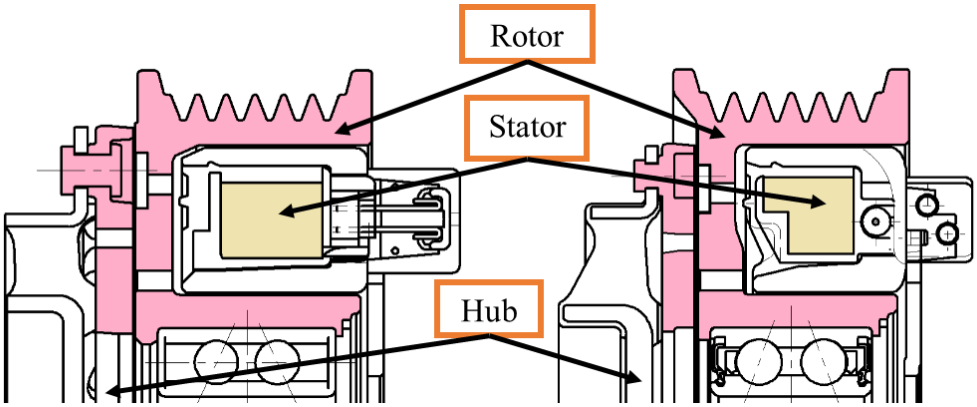


Figure 1: L50/LC45 Magnetic Clutch

Figure 2: LE40 Magnetic Clutch

When the air conditioner is ON, electric current flows through the coil inside the stator, forming a magnetic circuit between the stator, rotor and hub. After that, the hub is attracted to the rotor and transmission torque (frictional force) is generated transmitting the power of the rotor to the hub.
Then the power is transmitted to the compressor shaft connected to the hub and the compressor is driven. When the air conditioner is OFF, no current flows to the coil in the stator, so the hub is separated from the rotor and only the rotor rotates. In this way, the magnetic clutch transmits and disconnects power between the engine and the compressor.

DENSO's LE40 magnet compressor clutch is smaller, lighter, consumes less power but has the equivalent transmission torque as the conventional magnet clutch through:
(1) Minimizing coil wire diameter in order to reduce size, weight and power consumption
(2) Using a stepped coil design to reduce dead space in the motor and reduce coil size and mass
(3) Compensating the decreased in attractive force due to (1) by improving the magnetic circuit resulting in uniform magnetic flux density distribution and by reducing the magnetic resistance, in order to make the transmission torque equivalent.

As the result of this power saving, the reduction of the power consumption when using air conditioner, and the fuel efficiency of the vehicle have improved in comparison to the conventional magnet clutch.

Additional details of the system are documented in the Appendix A.

Rationale for Using Alternative Demonstration Methodology:

The off-cycle program was created to support the creation and adoption of new fuel saving technologies which reduce real world greenhouse gas emissions, but cannot be accurately captured in the traditional two cycle test. In the case of the LE40 magnet compressor clutch, the A/C is off during the EPA's two cycle testing for both city and highway. The LE40 technology is primarily designed to improve compressor efficiency, the A/C must be switched on to realize the benefit of the technology.

Of the EPA's 5- Cycle tests only the SC03 test includes the use of the A/C. The SC03 test is relatively severe test for A/C performance as it is conducted at 95 °F (35 °C), 850 W/m² solar load, and 40% relative humidity. This in conjunction with the short duration of the test creates a severe evaluation condition for the climate control system. As shown in the GREEN LCCP

model Version 3b, and national temperature trends, 95°F does not reflect the average conditions experienced by customers.

As this LE40 technology also provides benefits under milder ambient conditions when the A/C is not operating at maximum capacity, Toyota has chosen to pursue off-cycle credits under the alternative demonstration methodology pursuant to 40 CFR § 86.1869-12(d).

Proposed Alternative Demonstration Methodology

1) Calculation method and results of the power consumption

The power consumption of the magnet clutch is calculated from the resistance value of the clutch coil and the current value generated when a voltage of 12 V is applied. Toyota compared this power consumption from 20 different 2009-2012 compressors clutches from (5) suppliers without DENSO's LE40 magnetic compressor clutch technology under the same conditions and found an average power consumption reduction of 13 W. The results are shown in Table 2.

	All Supplier Ave	**DENSO LE40**
Power Consumed (W)	41.0	28.0

Table 2: Power Consumption Comparison

2) Calculation method and results of off-cycle credits value

To determine the CO_2 reduction potential of this DENSO LE40 magnetic compressor clutch Toyota used the calculation from the high efficiency exterior lighting credit outlined in the Joint TSD section 5.2.3. This calculation was further modified to update the vehicle miles travelled (VMT) from the lighting usage rate of 28.2% to the manual air conditioner usage rate outlined in the GREEN-MAC Life Cycle Climate Performance (LCCP) model. This model has been previously for approved for usage to calculate off cycle credit granted to Toyota for the Denso SAS compressor and the Denso S-FLOW system. This manual air conditioner VMT rate of 69% represents the worst-case condition compared to the automatic climate control VMT rate for variable compressors as the clutch is always engaged when the A/C is ON. For fixed compressors the clutch cycling rate needed to be considered when determining the VMT rate. To do this Toyota used bench test results for each of the LCCP model conditions to determine the clutch engagement rate for each condition and multiplied by the weighted national occurrence of each of those conditions. From this a weighted VMT for fixed displacement compressors being engaged was determined to be 34.6%. Given the LCCP's low assumption for Auto A/C usage rate, Toyota considered this a conservative estimate.

With the combination of the above two established methodologies Toyota used the following formula to convert of the reduced the power consumption the DENSO LE40 magnetic compressor clutch into CO_2 gram per mile reduction.

$$\Delta CO_2 = \frac{(Average\ Baseline\ Clutch\ Wattage - LE40\ Clutch\ Wattage) \times VMT\ fraction \times 3.2\ \frac{g\ CO_2}{mi}}{100\ Watts}$$

Based on this equation the requested credit value the following credit value was determined for variable displacement compressors.

$$\Delta CO_2 = \frac{(41.0\ W - 28\ W) \times .69 \times 3.2\ \frac{g\ CO_2}{mi}}{100\ Watts} = 0.3\ \frac{g\ CO_2}{mi}$$

The following credit value was determined for fixed displacement compressors.

$$\Delta CO_2 = \frac{(41.0\ W - 28\ W) \times .346 \times 3.2\ \frac{g\ CO_2}{mi}}{100\ Watts} = 0.1\ \frac{g\ CO_2}{mi}$$

Durability

Toyota Mobile Air-Conditioning (MAC) systems including the condenser, compressor, evaporator, thermal expansion valve and HVAC module, are required to pass stringent durability requirements to ensure a useful life time of the components. Testing includes meeting the rigorous 10 years/120,000 mile requirements to achieve the CO_2-related efficiency menu credits for both refrigerant-leakage and high efficiency A/C technology. Further durability testing on the HVAC module include door operation durability, vibration durability, thermal shock, high temperature durability, servo motor lock durability, dust durability and oil return.

Based on meeting these internal and EPA MAC durability requirements Toyota is confident that the LE40 magnet compressor clutch can meet the requirements for the vehicle lifetime durability with no degradation in the CO_2 reduction benefit of the LE40 magnet compressor clutch. Detailed results of the durability testing are included in Appendix D.

Conclusion

Based on the above bench test results Toyota hereby requests the following off cycle greenhouse gas credit for all vehicles equipped with this technology:

Technology	CO2g/mi Credit
LE40 magnet clutch variable displacement compressor	0.3
LE40 magnet clutch fixed displacement compressor	0.1

Table 3: LE40 Credit Request

This credit value has been estimated to be representative of the fuel economy improvement and grams CO_2 reduction associated with the use of LE40 magnet clutch in the United States based on the Life Cycle Change Performance model. Detailed model year, sales volume and the requested LE40 credit are included in Attachment E. Thank you in advance for your consideration.

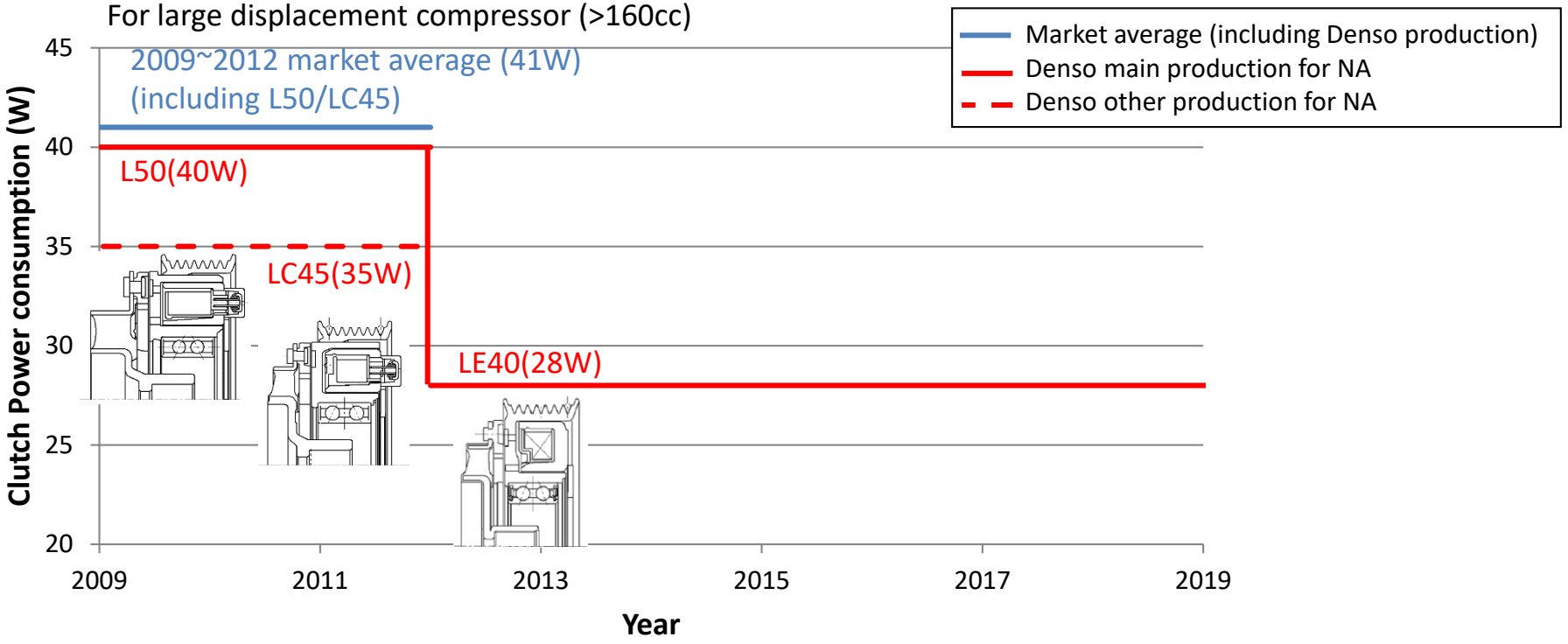
Toyota Motor North America Inc

Supporting Materials and Documentation

Appendix A: LE40 Compressor Technical Background
Appendix B: 2009 – 2012 Market Ave of Magnetic Clutch Power Consumption (Confidential)
Appendix C: LCCP Model A/C Usage Data
Appendix D: LE40 Compressor Clutch Durability (Confidential)
Appendix E: LE40 Compressor Clutch Toyota Vehicle Adoption Schedule (Confidential)

Appendix A: LE40 Technology Background

Market Trend of Clutch Power Consumption

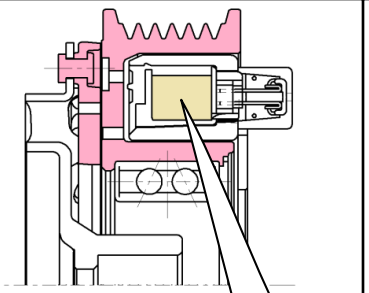
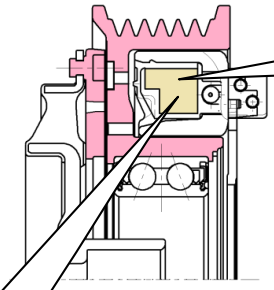


	Supplier A	Supplier B	Supplier C	DENSO		
Clutch type	-	-	-	LC45	L50	LE40
Power Consumption (W)	**40**(avg.)	**42**(avg.)	**42** (avg.)	**35**	**40**	**28**
Transmission Torque Capability (Nm)	55~59	35~50	52~56	41	53	41
Axial length(mm)	52~	47~	52~	47	52.5	45
Mass (kg)	2.2~	2.0~	2.1~	1.9	2.1	1.7

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.

Appendix A: LE40 Technology Background

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)

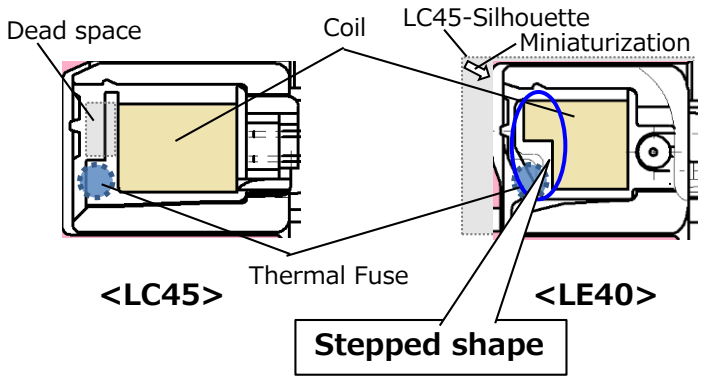
L50/LC45 (conventional design)	LE40 (optimized design)
	

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



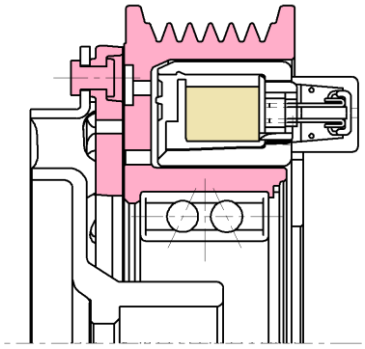
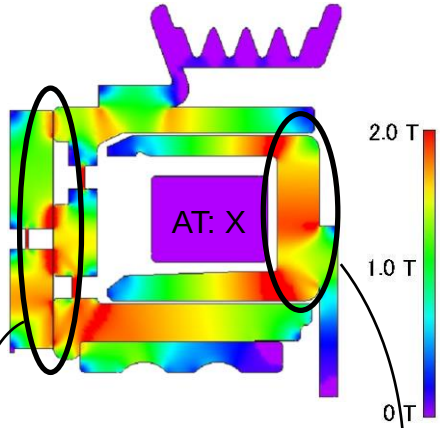
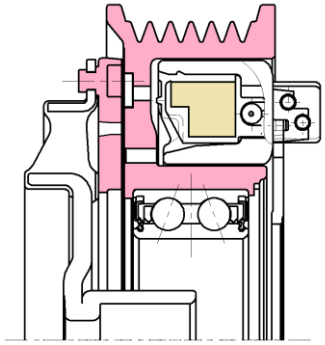
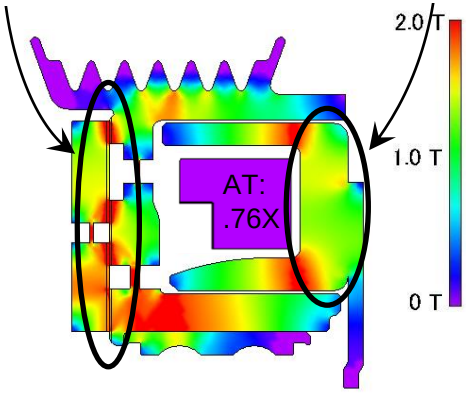
DENSO developed patented winding process to achieve a stepped coil design to reduce dead space and optimize coil size and mass.
※ Patent No. 3837786

Appendix A: LE40 Technology Background

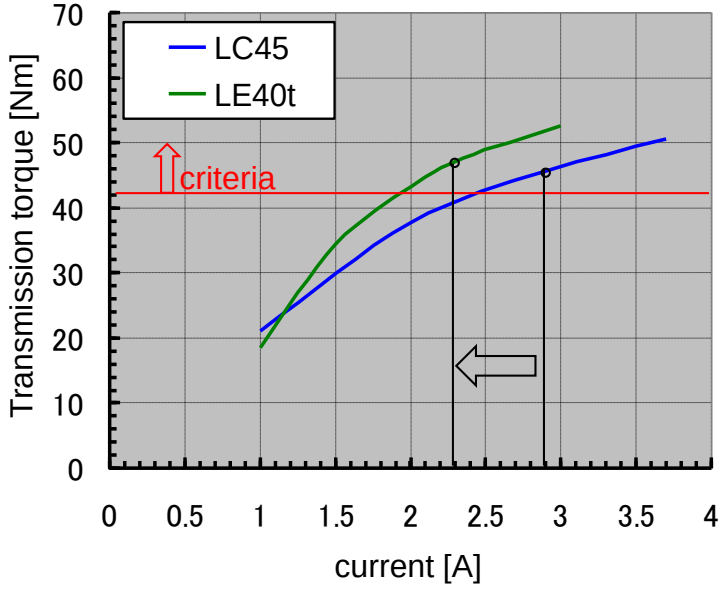
3) Improve Magnetic Circuit Design

- 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

	Cut View	Flux Density (CAE Result)
L50/LC45 (conventional design)		
LE40 (optimized design)		

Improve flux density distribution — **reduction of magnetic resistance**



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

Appendix C: LCCP Usage Data

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