Economy Climate System

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ABSTRACT

The paper presents the development of a project of an automotive embedded system, called ECS (Economy Climate System) the authors of this paper identified the need for improvement in the efficiency of the Climate System of the current vehicles, therefore was born the ECS project. The system was developed to contribute to the automotive industry so can be used in current and future projects of automakers. The system acts in conjunction with the conventional air conditioning system, increasing energy efficiency, the ECS keeps the vehicle cabin air conditioned even with the internal combustion engine off, increasing the autonomy of the vehicle, reducing power and fuel consumption, generating lower emissions of pollutants, greater comfort for the occupants, therefore being sized to act at points where automotive engineering needs constant evolution, improvement and new embedded systems. The system has as its development base the use of Thermal Module, electronic management of the onboard system, sensors, the calibration of the system developed from the variables needed for the system to work in an active way in vehicles with Start/Stop system, hybrid vehicles or electric vehicles, changing the software calibrations for each type of vehicle that the system should be implemented.

INTRODUCTION

Currently the automotive sector and mobility are in constant evolution, due to increased requirements of pollutant emissions, seeking greater efficiency of resources, the Rota 2030 is collaborating to this increase in efficiency and new technologies using even the implementation of technologies that were lost in the past and returned with as a great force as a trend that is already a reality in our market, such as hybrid and electric vehicles, with the advancement of technologies, we come across some setbacks, the ECS collaborates with the reduction of issues. [14]

Its scope is to act in vehicles with only Internal Combustion Engine (ICE) technology, hybrid and electric, the system was developed for a climate control system that acts with the ICE off, so it can be used in any of the types of vehicles, changing only the operation strategies.

The vehicles with an ICE system that has Start/Stop, hybrid and electric vehicles, have a deficiency where they have the climate system working or off, bringing a certain discomfort to the occupants and consuming a large amount of fuel in the case that is ICE with Start/Stop system. [7]

In the case of hybrid and electric vehicles, the compressor of the conventional climate control system works through the high voltage supplied by the set of batteries, its only source of energy (BEV), there causing a high consumption of electricity, reducing autonomy, especially in electric vehicles that is said by consumers and automakers, the expression "range anxiety" which is "anxiety by autonomy", in general, the conventional climate control system consumes a relatively large portion of this autonomy so important. [10]

In this way the paper was created to expose the developed system, ECS was developed from a market needs, where the vehicles ICE with Start/Stop, the moment that the system enters the strategy of Start/Stop the ICE turns off and must reconnect the moment that the driver needs, but the tropical climate of our country generates a great discomfort to the passengers of the passenger compartment with the rapid increase in internal temperature, so the strategy relog the ICE just to acclimatize the vehicle again, therefore generating a fuel consumption, emission of pollutants, among others. The ECS can be inserted in hybrid and electric vehicles, with a great economy of electrical energy when electric compressor, so the ECS is an innovative onboard system that can be implemented in the vehicles of the current market, bringing improvements to improve energy consumption, emission of pollutants, comfort of the occupants.

ECS and the conventional system of air conditioning work synchronously, the Air Conditioning System is responsible for reaching the temperature selected by the driver or passengers of the vehicle, after reaching the temperature the ECS starts working, deactivating the Compressor of the Air Conditioning, fed with a low electric current the Thermal Module of the ECS, where it will keep for a period the temperature of the passenger compartment as selected, without the need of the compressor to be working. The ECS was designed in order to full the mission of breaking a paradigm in air conditioning systems, which have low efficiency, although using Peltier Cells, the ECS will show the best between the two systems, increasing the efficiency of air conditioning and adding many significant advantages in energy efficiency in any type of propulsion technology. [1]

Throughout the paper we will be covering the theoretical concepts, development, practical result of the project, final considerations, reference, presentation of the authors.

DEVELOPMENT

ECS is an automotive onboard system that has the proposed solution to mitigate the deficits generated by the conventional air conditioning system, which has as its main composition a compressor that has a high power consumption, where in vehicles only ICE, this power is provided by ICE, so the Electronic Injection system needs to increase the time of fuel injection and ignition advance because of this power consumption, consequently the vehicle has higher fuel consumption, losing autonomy, increased emission of pollutants. When ICE is turned off the conventional Climatization System stops working, losing its comfort, and when the vehicle has the Start/Stop technology, it is constantly turned off, generating discomfort to the passengers.

The ECS was developed for use in HEVs and EVs, which have a conventional system where the conventional A/C compressor is powered by an electric motor that generates mechanical energy, not using power from the ICE, in the case of HEVs, but in most cases this A/C compressor electric motor uses electricity from the vehicle's high voltage system battery bank. Having a high consumption of electric current for the A/C system, this way, when turning on the conventional air conditioning system in the HEV, the consumption of electric energy increases, causing the ICE to use more fuel to compensate for this extra consumption of the A/C compressor, consuming more fuel, reducing autonomy and emitting more pollutants. In the EV when the conventional air conditioning system (A/C) is turned on, it consumes electrical energy from the vehicle's only source of energy, which is the battery bank, where the autonomy of the vehicle decreases exponentially, due to the consumption of electrical current needed by the A/C compressor.

Based on these deficits of the conventional climate control system, the ECS system is a possible solution to increase the efficiency of the climate control system, because the system works together with the vehicle's conventional system, having the function of increasing the time that the vehicle stays at the desired and comfortable temperature in the vehicle's cabin, without requiring the operation of the ICE, The Economic Climate System (ECS) has the purpose of being a less efficient climate control system than the conventional one, however, working with a consumption of electric energy much lower than the A/C compressor or consuming power from the ICE to the A/C compressor. [11]

With the practical validation of the ECS, we have a significant increase in the efficiency of the system when we use the conventional system together with the ECS. Basically, the ECS controls the operation of the A/C Compressor, because when it reaches the desired temperature or the vehicle turns off in the Start/Stop strategy the ECS turns off the Compressor activates the ECS thermal module, causing the system not to need the conventional system for a certain time, therefore increasing the efficiency of the system as a whole. The Chain Reaction generated by turning off the Compressor A/C is huge, because in addition to comfort, energy consumption is optimized in a considerable way.

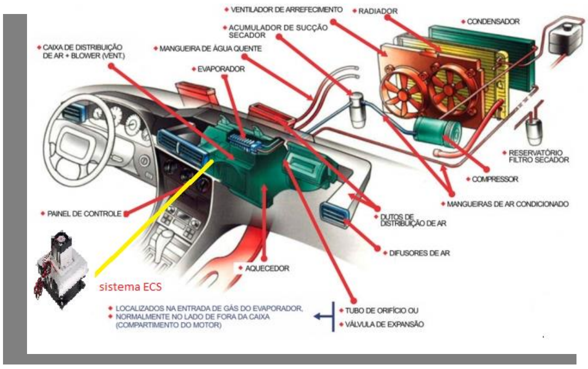
SYSTEM FUNCTIONING

The system has the principle of operation of the sensors and inputs feed the electronic management with information, the electronic management itself needs to put the logic of the strategies in operation, from this the electronic management sends the signal (output) so that the thermal module comes into operation.

The thermal module will be responsible for driving the Peltier cells and cooler, always inspected by a temperature sensor in its constitution, to evaluate the system's operation, generating feedback for the electronic management.

LOCATION

The location of the ECS is the main characteristic of the Embedded System, because the processor can be inserted wherever it is needed, to make it easier and not increase the amount of hardware the system can be implemented next to the Body Module already existing in the vehicle, being simpler to implement the system, since its heat exchanger module is installed in series with the tubing of the internal aeration system of the vehicle, because this way it does not occupy more space in the passenger compartment, keeping it covered by the vehicle panel, and it can have a thermal module for each one of the diffusers, obtaining an advantageous efficiency.



(Figure 1. ECS Localization and Conventional System)

CONSTITUTION OF EACH SYSTEM COMPONENT

The system basically consists of three sets of components, Electronic Management, Thermal Module, and Sensors.

ELECTRONIC MANAGEMENT

Consisting of a microprocessor calibrated for strategies according to the type of system that the vehicle uses, changing only the software, with the insertion of the embedded system in the body module, the amount of hardware, cabling and cost is reduced, since important information provided to the CAN network that will be important to the ECS is easily accessible in the body module. The Microprocessor programming, initially was elaborated from the flowcharts, according to the type of vehicle, being ICE with Start/Stop, hybrid or electric.

The electronic management follows the pre-defined strategy, from switches, sensor signals, acting in the thermal module, because from the inputs received from the air conditioning system, the system receives information from other systems that are extremely important for the system through communication networks, where most of them from the CAN network, therefore calculating the variables and controlling the thermal module to start or turn off and reactivate the A/C compressor

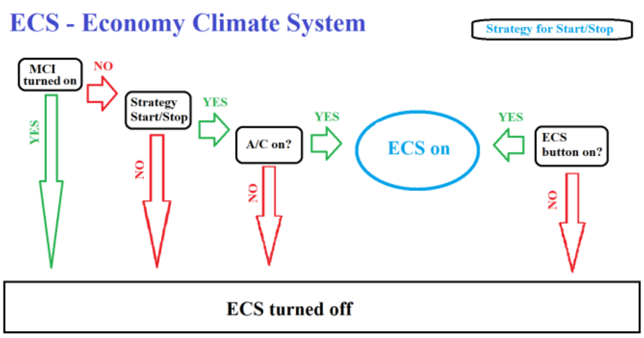
Inputs: ECS switch, A/C switch, Engine speed sensor if ICE, External temperature sensor, Cabin temperature sensors, Thermal Module temperature sensor, A/C control unit, CAN network, Electric motor if hybrid or electric.

Outputs: Thermal Module, A/C Compressor.

The A/C management, being an embedded system, the ECS has all the characteristics of any embedded electronic system, and can be accessed by an automotive scanner for diagnostics and tests, so when a component of the system generates a defect, the electronic management will store a DTC in its memory that must be accessed by scanner, therefore generating more reliability in the system, facilitating the diagnosis, reading parameters, and therefore increasing reliability.

The basic strategies of the project are cited in a simple way below through flowcharts, there are many other variables, however, presenting in a simple way the functioning of the ECS.

Start/Stop



(Figure 2. ECS Flowchart for ICE Start/Stop)

The figure above is a flowchart of the operation of the system with Start/Stop, exemplifying a simple logic of the system, and the strategy can be implemented in vehicles with Start/Stop and HEV, which use Compressor A/C driven by auxiliary belt connected to the ICE, therefore being a more coherent strategy to the system.

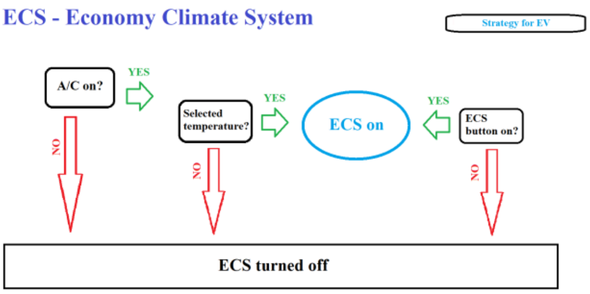
Through the CAN Network the system uses the rotation signal from the ICE, and several others, therefore identifying if the vehicle is on or not. If the ICE turns off, the system needs to identify if the Start/Stop system is active and the A/C is on, the ECS should be turned on, therefore increasing the time with pleasant temperature inside the vehicle without the ICE operation.

In case the ICE is in normal operation and the temperature of the passenger compartment is in the coherent temperature selected by the driver, the ECS goes into operation, in the strategy of maintaining the temperature without the compressor, that is, from the moment the ECS is activated, the compressor is automatically turned off, by cutting the electric current of the magnetic clutch, electromagnet, of the conventional A/C compressor. This reduces the power consumption of the ICE.

The system can also be activated directly through a switch of easy access for the driver, working only the ECS for air conditioning, therefore bringing the financial and ecological advantages already mentioned.

EV Strategy

For electric vehicles the strategy changes, because it has no ICE, so the compressor of the conventional A/C needs an electric motor that uses the continuous high voltage supplied from the vehicle's battery bank, bringing as a issues a high consumption of electricity, the only power source (in normal use conditions, therefore, the ECS can be used to reduce the consumption of this energy, increasing the autonomy of the vehicle, compared to the use of conventional A/C, where the consumption of electric current is very large, because of the power required to rotate the A/C compressor.



(Figure 3. ECS Flowchart for EV)

In the EV the ECS works as a system that maintains the temperature of the passenger compartment, the operation of the conventional A/C system enters into operation, until the temperature selected by the occupants of the vehicle, when selected the ECS starts its operation, maintaining the desired temperature for a longer time, this time will vary according to the temperature selected by the driver. Instantly, with the start of the ECS, the power to the compressor of the conventional A/C is turned off, therefore reducing the consumption of the vehicle's only source of energy and leaving the passenger compartment air-conditioned and with a low consumption of energy from the vehicle's battery bank.

Through a switch accessible by the driver, the ECS can be activated directly, leaving the use of the conventional Air Conditioning System, therefore decreasing the temperature of the passenger compartment with low energy consumption, but low efficiency compared to the conventional system.

HEV Strategy

There are several types of HEV, the ECS can be implemented in each of them, because it uses the traction of an electric motor and ICE in the same vehicle, varying the level of performance and hybridization of each, however we can use the ECS with the union of the above strategies.

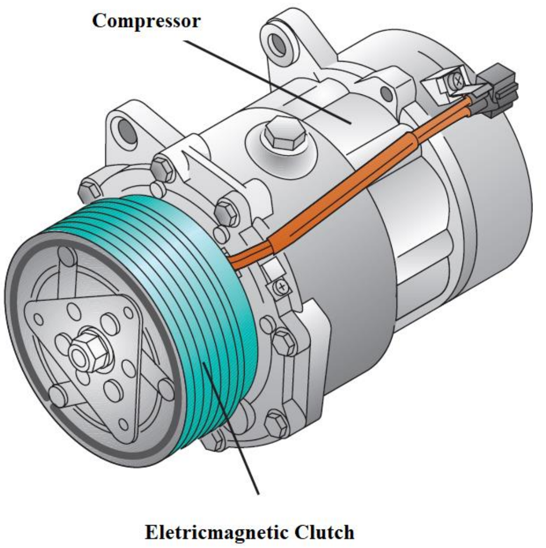
HEV Mild Hybrid the system will work in the same way as the ICE Start/Stop system, because its main source of energy is provided by the ICE, and the motor-generator is only an electric help for the vehicle (Boost).

Full Hybrid uses the same strategy as EV, in most vehicles already have the A/C compressor, driven by a high-voltage electric motor, different from the ICE that uses the power of the ICE, consuming fuel, emitting pollutants and other setbacks.

However, like the other systems, the HEV also has a switch with direct activation of the system, bringing greater control of the driver and occupants of the vehicle, therefore greater comfort and choice for the occupants of the vehicle.

Below the Compressor of the A/C with emphasis to show the Electromagnetic Coupling, which has the function of transferring the movement of the accessory belt from the ICE to the compressor, so when powered it works as an element of transmission of mechanical energy of the engine rotation to the internal part of the compressor, however, consuming power from the ICE, increasing fuel consumption.

In the case of the picture, it is used in ICE, but in HEV Full and EV vehicles they use an electric motor to rotate the compressor of the conventional A/C.



(Figure 4. Conventional A/C Compressor with Electromagnetic Clutch)

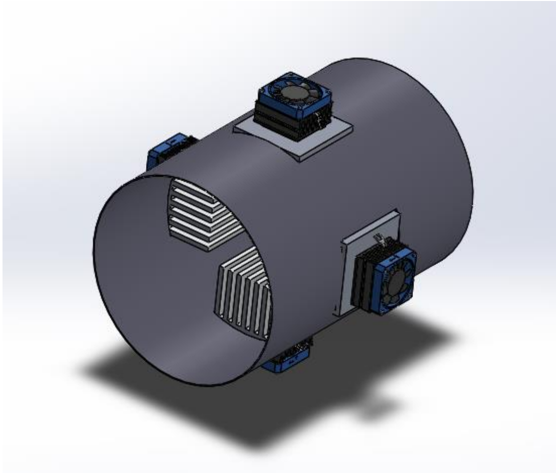
Thermal Module

Constituted by a central aluminum heat exchanger, because it has a good heat energy exchange, where Peltier cells (thermal cells) are installed, for the validation of the low fidelity prototype we used the 1206 cells, leaving the side that absorbs thermal energy (cold side) facing the central heat exchanger. The other side that dissipates heat (warm side), should be installed coolers, controlled by the microprocessor, to dispense the higher temperature, through pipes, being directed out of the vehicle. [2][4]

It is necessary to have a good dissipation of this higher temperature, because the temperature if not dissipated will affect the efficiency of the Thermal Cell, therefore not working in the best way, so we will see below the constitution and characteristics of the Thermal Module. [5]

In the ECS onboard system, the Thermal Module is the main actuator of the system, because who does its control is the electronic management, activating and turning off the Thermal Module when necessary, regulating the efficiency of its operation, therefore, Thermal Module can be dimensioned with only one central Thermal Module or small modules for each duct, having a greater control and greater efficiency, greater control of temperature by zones, varying according to the design of each vehicle and classification of the vehicle.

Below, a drawing made by the authors of a prototype of the thermal module, with no need to be exactly like this, therefore, it can be designed in the way that is necessary for each type of project, being necessary to maintain the location of the thermal module, the Thermal Cells, dissipators and coolers.



(Figure 5. ECS System Module)

The Thermal Module's housing is to make the coupling of the heat sinks, cells, containing all its dimensioning, its construction material is aluminum, because it is a great material for heat exchange, specific weight considerably light and its cost. Therefore, possessing a good cost x benefit for the onboard System, being more advantageous for application in scale in vehicles.

The Peltier cell used in the prototype was the 12706, which has the essential characteristics and parameters to validate the project. Once the ECS is validated, the cells can be altered to improve their efficiency, meeting the automaker's demands.[12]

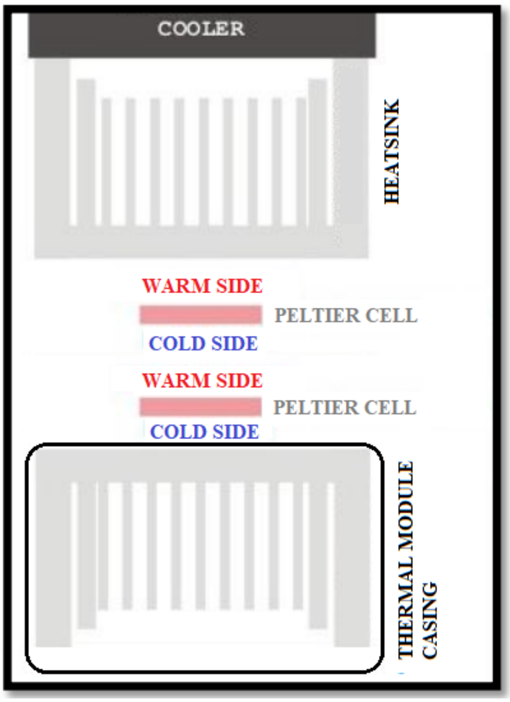
The heat flow transfer to the P and N elements takes place as follows: The positive P element absorbs heat raising its energy level which makes it migrate to the hot side that has a lower amount of energy. Through fans, coolers and sinks, heat is removed from this element that returns to the P side restarting the cycle. [15]

Cooler to remove heat generated by the Peltier Cell, extremely necessary for the system, because if there is no removal of this heat, the system will be compromised completely, because the heat not dissipated, through convection, will transfer to the opposite side of the Cell, here it should be a low temperature in normal work. [6]

(Figure 6. Cooler)

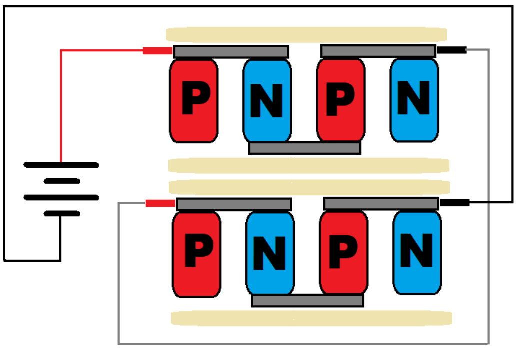
The Electrical Connection of the Thermal Module Cells were sized through practical experiments, we obtained greater success between the electrical connections of the cells with the connection of two cells one over the other, with a serial electrical connection as explained below.

The first image shows the physical connection of the Peltier cells, where dimensioned to improve the efficiency of their work, aiming at a better efficiency of the project itself, from the reasoning and practical experimental tests, we arrived at the best physical connection in this way: the cells are fixed one on top of the other, in a way that connects the side that removes heat (cold side), of the semiconductor with the side that dissipates heat (warm side), therefore potentiating its initial work of removing heat from one side and dissipating heat from the other.



(Figure 7. Physical connection diagram of Peltier Cells)

The electrical connection was made with the principle of electrical connection in series, which has as its principle the connection of the positive connection of a cell with the negative of the other cell, therefore making the connection between consumers, as the negative power supply of the set of consumers, was performed directly, however the positive power supply of the set of cells was made through the electronic management that feeds a mini automotive relay that this yes, feeds the positive part of each set.



(Figure 8. Electrical connection diagram of Peltier Cells)

Sensors

The system has sensors that read certain important data for the perfect operation of the system, moment of operation, intensity. The main sensors can be used the same already present in the conventional A/C, using them as reference for the electronic management of the ECS, using the CAN network protocol or the communication network present in the vehicle, so it will not be necessary the considerable increase of sensors, because it has as a characteristic the distribution of data in high speed and not being necessary the insertion of many more sensors. Designed for this, the system will use only one more sensor, the Temperature Sensor from the output of the ECS Thermal Module, which uses an NTC thermistor type to inform the electronic management about the temperature.

The main sensors used via the communication network are: Outside air temperature sensor, fresh air inlet temperature sensor, cabin temperature sensor, ICE rotation sensor, clutch pedal sensor, brake pedal sensor and other sensors according to the vehicle type and its characteristics, in this way can be inserted in the ECS base strategies.

INPUTS

The Inputs, that is, readings of signals from switches, buttons, and sensors, necessary for the system to function optimally, enabling better control of the system, increasing the reliability and effectiveness of the ECS. Addressing some of these Inputs below in each paragraph:

The ECS switch is as function, enable and disable the ECS manually, in this way delivering a manual control for the passengers, consequently giving the choice option for the exclusive use of the ECS, without the operation of the Conventional Climate System, or even let the system work with its best efficiency, that is, the junction of the conventional system with the ECS.

The conventional A/C switch is necessary to know if it is on or off, because according to its state, on or off, the ECS system can work or not, therefore this Input is extremely necessary for the precise operation of the ECS.

OUTPUTS

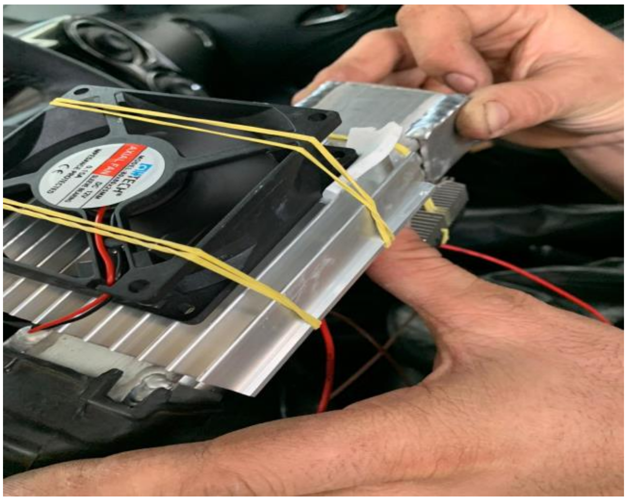
The Outputs are the outputs of commands that electronic management needs to act, therefore, as previously analyzed, the Thermal Module is an actuator that requires the electronic management command.

The command system of conventional A/C, is another component that must be commanded by electronic management, because when the ECS system comes into operation the conventional A/C should be turned off so that there is no waste of energy, both the engine, as electric, because the systems should work in parallel, but each at a time. [3]

PROJECT VALIDATION

To validate the functionality of the ECS system, we built a low-fidelity prototype in order to validate the system's operation. Therefore, the validation was performed using the following experimental method: with the vehicle, Toyota Etios model, in operation, with the passenger compartment closed, external temperature of approximately 28ºC, and with two people inside the passenger compartment, the conventional air conditioning was activated until the outlet temperature of 0ºC (air) was reached, (approximately 15ºC in the ambient temperature of the passenger compartment).

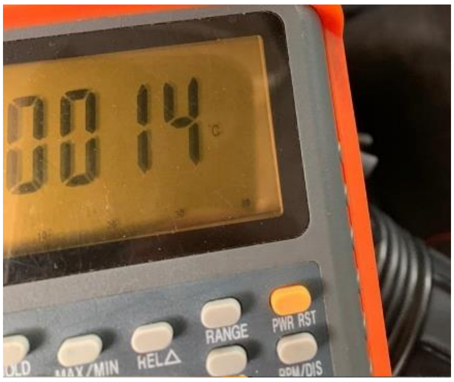
After the temperature of 0ºC was reached at the air outlet, the conventional air conditioning was deactivated, but the air conditioning fans still continued to work, simulating a supposed stop in traffic, therefore being possible to quantify the increase in air temperature at the ducts outlet over time, with the ECS system working and without the system.



(Figure 9. ECS Prototype)

(Figure 10. ECS system validation method)

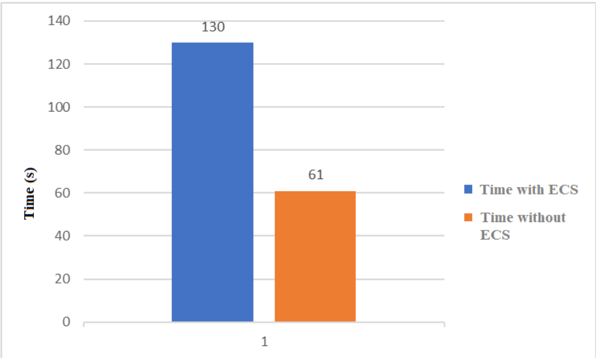
Therefore, it was found that the air at the exit of the ducts in both cases with initial temperature of 0ºC and final temperature of 14ºC, had very different times for this temperature variation without the use of the ECS system the time was 61 seconds, while with the use of the system the time was 130 seconds. That is, in this specific case the ECS system managed to increase the time of temperature variation by 69 seconds.



(Figure 11. ECS system temperature)

Therefore, the system empirically proved its functionality, the electric current consumption was measured during the experiment, where the 6 cells connected in two in series generated a real consumption of 4.2 A.

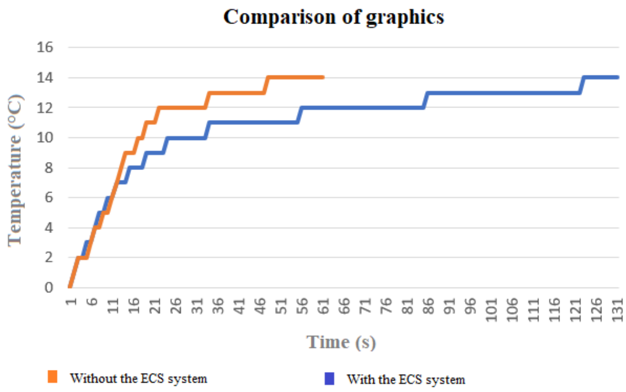
(Figure 12. Consumption of the ECS system)



(Figure 13. Time with and without the ECS system)

DATA ANALYSIS

According to the experiment performed, the air temperature variation at the duct outlet was 113% lower with the use of the ECS system, in other words, the temperature took longer to increase. Below the time and temperature are represented in a simple graph, the first without the use of the ECS system and the second with its use, and then a comparison between the graphs.



(Figure 14. Comparison with and without the ECS system of time vs. temperature when A/C is turned off)

The energy efficiency of the system was satisfactory since the electrical current consumed by the module (composed of six cells and two coolers) was only 4.2 A. As we used a voltage of 12 V to feed the system, the electrical power used by the module was only 50.4 W.

Very low power compared to a traditional air conditioning system that ranges from 5500 W to 11000 W, taking into consideration the installation of more ECS modules to supply the demand of the cabin (on average six modules) the power consumed by the ECS system would be 302.4 Watts, or approximately 2.8% to 5.5% of the power consumed in a traditional system.

Advantages x Disadvantages ECS	
Advantages	**Disadvantages**
Low energy consumption; Increased comfort for vehicles with Start/Stop; Reduced size and mass; Low cost; Easy implementation; Simple components; Higher efficiency in the overall system; Lower fuel consumption	System requires conventional A/C; Low Heat Flow (compared to A/C); Low Efficiency (without A/C); Low weight increase.

Lower emission of pollutants; Increased autonomy in EV and HEV.	

(Table 1. Comparison of advantages and disadvantages)

SYSTEM PERFORMANCE

The ECS was developed in order to correct a setback caused in the Start/Stop System, that by characteristic of the same and tropical climate, the vehicle when turned off, the conventional air conditioning system consequently also stops working because of one of its main components, the compressor, need the rotation mechanical energy generated by ICE, therefore causing discomfort to the occupants in the hottest days. However, in order not to decrease too much the comfort of the occupants the ICE would work again, even before it was necessary, just to generate energy for the A/C compressor, therefore the ECS acts in the main aspects of the vehicle, which are comfort and reduction of pollutant emissions.

From the premises above, through research, calculations, case studies and simulations we proved a relatively considerable efficiency for the environment, in other words, maintaining the comfort of the vehicle for the occupants. At first, we used as reference an ICE vehicle that has the Start/Stop technology implemented in the vehicle, in itself the Start/Stop already presents a large percentage of improvement, consumption and consequently emission of pollutant gases, harmful to health.

Some important data of the Start/Stop system, the system can reach an optimization of approximately 15%, and can reach possible 20%, of fuel consumption and emission of CO^2, varying according to the traffic, climate, geographical relief. When the vehicle is with the conventional A/C system on and the strategy starts the Compressor stops working, the cabin ventilation system continues working, however the tropical climate raises the cabin temperature in a few seconds, so when the cabin temperature sensor informs a considerable temperature increase, the A/C management determines that the ICE starts working, regardless of the driver's movement on the pedals. The ECS in turn has the function of increasing this time, so that the ICE does not turn on again, therefore consuming fuel, emitting polluting gases and even noise pollution, just for comfort. Based on this information, we simulated a vehicle running in heavy traffic and made a comparison with calculations between the ICE Start/Stop vehicle and another with the same characteristic, but with the ECS.

QUANTIFICATION OF CO^2 EMISSION REDUCTION WITH THE ECS SYSTEM

<u>Characterization of a route using the ECS system</u>

In a route in the city of São Paulo in a situation of intense traffic, the start-stop system can contribute to reduce the emission of about 20% less CO2 in the atmosphere, however, when the vehicle is stopped with the engine inoperative for a long period of time, the temperature of the passenger compartment begins to increase, because in this system when the vehicle turns off the engine with the air conditioning on, only the ventilation system is maintained.[8]

The ECS system fills this gap so that the engine does not run again just to maintain the comfort of the cabin in the period when it is stopped, increasing the sustainable performance of the start-stop system.

To quantify the reduction in carbon dioxide (CO2) emissions, the Top-Down method was applied. This method is adopted by the Brazilian government for the preparation of the national inventory of pollutant gases and was developed by the Intergovernmental Panel on Climate Change (IPCC). [16]

The method has three steps in order to calculate the real CO2 emission.

Conversion to Common Unit

All fuel consumption measurements must be converted to a common unit using Equation (1):

(1) CC = CA*Fconv*41,868*10-3 *Fcorr

Where: CC: energy consumption in Tera–Jaule (TJ);

CA: consumption of fuel (m3);

Fconv: conversion factor of the physical unit of measurement of the quantity of fuel to toe (ton equivalent petroleum), based on the superior calorific power (PCS) of the fuel. According to Ministry of Science and Technology (MST) data, the Fconv values are: gasoline (0,77 toe/m3); hydrated alcohol (0,510 toe/m3); diesel (0,848 toe/m3);

Ton of oil equivalent (toe): Unit of energy used to compare the calorific value of different forms of energy with petroleum. One toe corresponds to the energy that can be obtained from one ton of standard petroleum. 1toe = 41,868 x 10-3 TJ (Tera-Joule =1012J).

Fcorr: correction factor from HHV (gross calorific value) to LHV (net calorific value). In BEN (National Energy Balance) the energy content is based on the PCS, but for the IPCC the conversion to a common energy unit must be done by multiplying the consumption by the PCI.

For solid and liquid fuels, the Fcorr = 0,95 and for gaseous fuels the Fcorr = 0,90, according to the MST.

Carbon Content

The amount of carbon emitted when the fuel is burned must be calculated according to Equation (2):

(2) QC = CC*Femiss

Where: QC: carbon content expressed in tons of Carbon (tC).

CC: energy consumption in Tera Joule (TJ);

Femiss: carbon emission factor (tC/TJ). The IPCC (1997) values of the Femiss are: gasoline (18.9 tC/TJ); hydrated alcohol (14.8 tC/TJ); diesel (20.2 tC/TJ).

CO2 Emissions

Finally, the CO2 emissions are calculated according to Equation (3). Since the molecular weight of Carbon is 12 and Oxygen is 16, therefore the molecular weight of carbon dioxide (CO2) is 44. Therefore, 44CO2 corresponds to 12 tC or 1 t of CO2=0.2727tC according to Equation (3):

(3) ECO2 = QC*44/12

Where: ECO2: emission of CO2;

QC: Carbon Content.

Case Study

Proving the efficiency of the system, through numerical calculations, comparing the emission of pollutants between a gasoline vehicle without ECS and with ECS, proving the notable difference between the two systems.

Considering a gasoline vehicle, we can simplify the equation as follows:

(4) Emission (tCO2) = 0,002122412*CL

Where: tCO2: emission de CO2 in tons;

CL: Fuel consumption in liters.

In a daily route of 20km, 5 times a week with a vehicle with an average urban consumption of 10km/l, in the period of a year (considering approximately 52 weeks) you will have a consumption in liters according to the following calculation:

CL = (20*5*52) /10

CL = 520 liters

By substituting in the emission formula, we can know the amount of CO2 emitted by this vehicle in the period of one year:

Emission = 0,002122412*520

Emission = 1,10 tons de CO2

Whereas a vehicle equipped with the ECS system will ensure that the vehicle's start-stop system acts with maximum efficiency, the vehicle will stop emitting 20% less CO2, applying in the example:

CO2 Reduction = 1,1*0,2

CO2 Reduction = 0,22 tons

With the ECS system just one vehicle would stop emitting 220 kilograms of CO2 into the atmosphere in one year. A considerable factor, considering the use in medium and large scale, especially in large urban centers and metropolises.

From the calculations presented, the ECS is an embedded system that delivers comfort and reduces the emission of pollutants and can be implemented in the most technological vehicles, having options and strategies for hybrid and electric vehicles.

Energy Consumption

In HEV and EV vehicles, the entire electric consumer should be well sized because of autonomy, in a conventional vehicle the air conditioning system can consume about 5hp because the compressor is directly connected to the vehicle engine, with HEV and EV vehicles we do not have the reduction of engine power, but its autonomy, in some systems we have compressors similar to those used in conventional systems where brushless electric motors are used, fed directly from the vehicle inverter to drive the compressor (Toyota Prius).

In some fully electric models (Nissan Leaf) use the electric air conditioning system, where the compressor is connected directly to the vehicle's battery, but this system is expensive, which makes it difficult to use in vehicles with start-stop system, for example.

In the example, we will use the Nissan Leaf data to calculate the effect of comfort on the range of an electric vehicle, the Nissan Leaf has an average range of 240km using a battery that can deliver 40KWh. The electric air conditioning system consumes about 1100W at 12V which represents 2.75% of the total battery range considering the Nissan Leaf data, this means that the car will travel 6.6km less using this air conditioning system.

The ECS system has an average consumption of 4.2 A per air duct, on average a conventional vehicle has four ducts for the air output for occupant comfort (front ducts, two located in the center of the vehicle panel and one on each side of the panel), equation (1) represents the calculation of the total system power in relation to the number of ducts, considering the system powered by 12V:

(5) PT ECS (W) = 4,2 x V x QD

Where: PT ECS: Total power of the ECS system, in watts;

4,2: Constant of the system consumption per duct, in amps;

V: System power supply voltage;

QD: Number of ducts that have the ECS system installed.

Substituting the values gives the following results:

PT ECS (W) => 4,2 x 12 x 4 = 201,6W

The ECS system has a consumption 81.67% lower than the electric air conditioning system, as the idea of the ECS system is to be a hybrid with the main air conditioning system of the vehicle, in the case of the electric vehicle, after the air conditioning system lowers the temperature to the desired one, the ECS system comes in to maintain the temperature, causing the compressor to start running less frequently, increasing the autonomy of the electric vehicle.

Consequently, the project becomes an onboard system that can be made viable by automakers because in the case of vehicles with compressor of the electric A/C, used in EV and some HEV, the ECS is a system that can mitigate approximately 8% of vehicle costs for the automaker, because if we keep the same autonomy and ECS implemented in the vehicle, one can design the battery bank to a lower capacity, decreasing cost and weight of the vehicle, the cost of the Wh of the battery is a considerable value to the total value of the vehicle, so with the implementation can be a downsizing in the battery, keeping the same autonomy, decreasing cost and weight of the vehicle, a scaled down cooling system for the battery designed to lower capacity. [13]

FINAL CONSIDERATIONS

The ECS onboard system becomes a system for the vehicles, bringing to the consumer a greater comfort of ICE vehicles with Start/Stop and an increase in autonomy of EV and HEV vehicles as proven in the paper, contributing to Automotive Engineering.

The chain reaction with the use of ECS is very interesting because it adds value to the vehicle in a way that is advantageous to the consumer, car manufacturers or systemists, an embedded system that acts positively on the main deficits of the global automotive industry, with all the advantages mentioned. The calculations show hard saving for immediate deployment by the automotive industries, making it a potential system to be introduced at scale in the world fleet.

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