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Influence of Automotive Air Conditioning load on Fuel Economy of IC Engine Vehicles

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Abstract— Recently, scientists at the National Renewable Energy Laboratory (NREL) in United States were able to figure out that United States could save over $6 billion annually if all the light-duty vehicles in the country achieved a modest 0.4-km/L (1-mpg) increase in fuel economy. Their study also showed that the US uses 27 billion liters of gasoline every year for air conditioning vehicles. Factors affecting the AC load on the engine include climatic conditions, cabin conditions, compressor speed, difference between the climatic (outside) conditions, and overall efficiency of the AC system etc. The opportunities to reduce this AC load on the engine include thermal load reduction by use of advanced window glazing & parked car ventilation, the use of seat based climate control, recirculated air & by application of alternative cabin cooling techniques. By the application of these techniques significant reduction in the AC load can be achieved which will benefit us especially because of the large number of new cars sold each year. In a country like India where fleet penetration has reached a high level, we can save substantial amount in foreign exchange & reduce the dependence on crude oil imports & reduce the extra atmospheric pollution caused due to the use of automobile air conditioning systems. Therefore, reductions in automotive air conditioning loads on the engine are quite clearly the need of the hour, making tomorrow's vehicles more fuel efficient, while keeping passengers comfortable.

Index Terms— Automotive air conditioning, Air Conditioning load, AC, R134a, reduction in fuel economy, impact of air conditioning on fuel economy, potential solutions for reduction of AC load on engine.

1 Introduction

THE fast depletion of crude oil reserves, frequent price hikes of crude oil & the high atmospheric pollution have created a worldwide need to reduce petrol and diesel consumption particularly in the automobile industry. Just recently scientists at the National Renewable Energy Laboratory (NREL) in United States were able to figure out that United States could save over $6 billion annually if all the light-duty vehicles in the country achieved a modest 0.4-km/L (1-mpg) increase in fuel economy [2]. Their study also showed that the US uses 27 billion liters of gasoline every year for air conditioning vehicles, equivalent to 6% of domestic petroleum consumption, or 10% of US imported crude oil [1]. This paper discusses the significance of automotive air conditioning loads on I.C engine vehicles, its impact & the multiple ways to reduce the amount of energy spent for cabin environment control. It was found out that the current air conditioning systems reduces the fuel economy of a conventional vehicle by at least 1.52 km per liter , and has an unacceptable impact on high fuel economy vehicle where the mileage was found to be reduced by 2.74 km per liter. The opportunities to reduce AC load on the engine include thermal load reduction by use of advanced window glazing & parked car ventilation, the use of seat based climate control, recirculated Air & by application of alternative cabin cooling techniques.

2 Factors Affecting the Air Conditioning Load on the Engine

2.1 Climatic Conditions

This consists of outside environmental conditions such as Temperature, Pressure, and Relative Humidity. The outside conditions play a huge role in determining the air conditioning load on the engine. The multiple governing parameters of the cabin thermal comfort such as the solar incidence angle, the glass/glazing properties, the surrounding radiant heat and air velocity, affect the HVAC system performance. Larger the difference between the above factors, larger is the load on the engine. In case of larger difference between the outside environmental and cabin conditions, the compressor has to do more work in order to isolate the cabin from the outside environment. If the difference is smaller then the compressor will have to do less work, which results in lesser power drawn from the engine for air conditioning purposes.

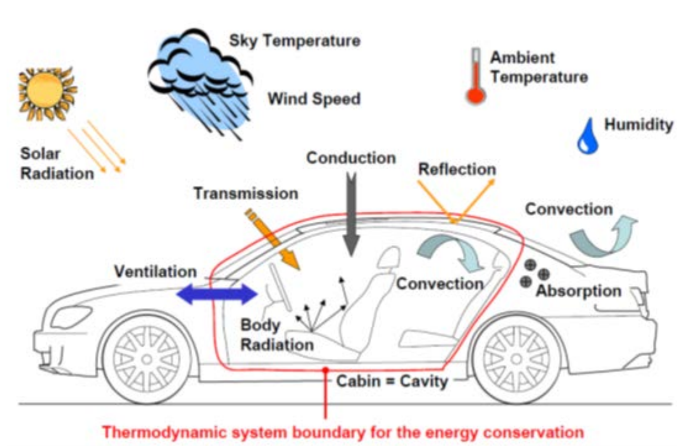

Fig. 1, Physical parameters and heat transfer modes that effect on passenger compartment [6]

2.2 Cabin Conditions

The inside conditions also play an important role in determining the auxiliary load on the engine of a vehicle. Ex: - Higher Peak cabin soak temperature will result in larger load on the engine.

Cabin conditions are also affected by Latent Heat gain & Sensible Heat gain due to various heat sources both inside and the outside of the car. The auxiliary load is also affected by the number of passengers in the cabin, by increasing the number of passengers in the cabin, the time interval for reaching the adjusted cabin air temperature is shorter. The non-uniformities associated with the cabin thermal environment due to the air temperature distribution, the solar flux, and the radiation heat flux from the cabin surrounding interior-trim surfaces, complicate the conditioning process. Furthermore, the multiple governing parameters of the cabin thermal comfort such as the solar incidence angle, the glass/glazing properties, the surrounding radiant heat and air velocity, affect the HVAC system performance. In addition, the psychological as well as physiological difference among the passengers is also plays a role. Finally, the variation in passengers thermal loads in terms of; thermal sensation, clothing, number of passenger, metabolism rate, hinders the system robustness. So, the vehicular climatic control systems suffer from previous distinct challenges [6].

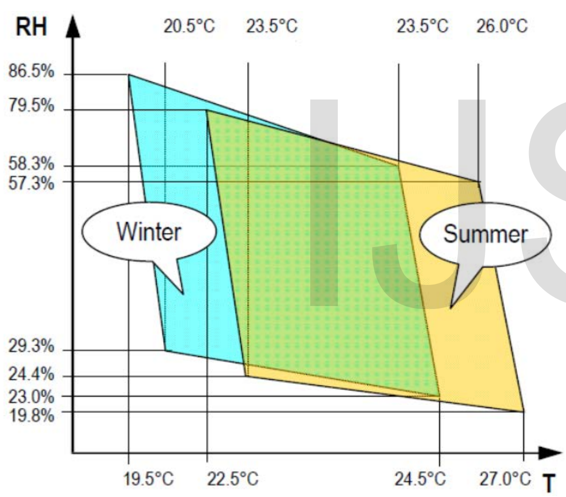

Fig. 2, Relative humidity (RH)/temperature (T) diagram based on comfort zone [6].

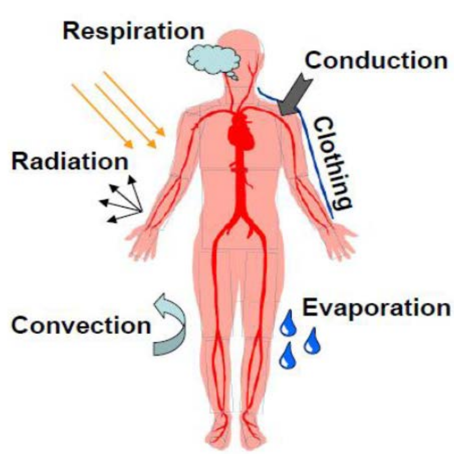

Fig. 3, Physical parameters and heat transfer modes that effect on passenger compartment [6].

2.3 Compressor Speed

Most of the compressors used in Indian cars are mechanically driven. And Compressor speed is directly proportional to the load on the engine. As due to lower compressor speed during idling operation mode, lower valued of refrigerant mass flow rate passes through the evaporator, which also means less amount of AC load on the automobile engine.

2.4 Difference between Climatic and Cabin conditions

Larger the difference between the above factors, larger is the load on the engine. In case of larger difference between the outside environmental and cabin conditions, the compressor has to do more work in order to isolate the cabin from the outside environment. If the difference is smaller, then the compressor will have to do less work, which results in lesser power drawn from the engine for air conditioning purposes.

2.5 Overall Efficiency of the Air Conditioning system

The Overall efficiency of the air conditioning system is affected by-

a) **Type of Compressor used-** Electrically driven compressor used in high end vehicles are more efficient than the mechanical counterparts. i.e. electrically driven compressors need less energy to drive the whole refrigeration system than the mechanically driven compressors to do the same amount of work.
b) **Type of Evaporator used-** Tube in Tube type Evaporators have the maximum efficiency.
c) **Type of Condenser used-** Evaporative condensers have higher efficiency than the other type of condensers.
d) **Type of refrigerant used-** Refrigerant having higher critical temperature, pressure, thermal conductivity & latent heat of vaporization will result in lesser load on the engine. Currently, the refrigerant used in almost all of the vehicles is R134a. Though this refrigerant (R134a) has zero Ozone Depletion Potential (ODP), the concern is its high Global Warming Potential.(GWP)
e) **Vehicle speed-** There is also a significant decrease in air conditioning efficiency with higher vehicle speed especially in mechanically driven compressors. The figure below shows variation of cabin air temperature for 40km/hr, 80 km/hr, 100km/hr and idle (zero) speeds, the cabin air temperature is lower than the idling operation mode throughout the test. With increasing the vehicle speed from 40km/hr to 80 km/hr and then 80 km/hr to 100km/hr, there is no significant change in cabin condition and convection heat transfer rate. Therefore, no significant change in cabin air temperature is obtained. For all 40,80,100 km/hr cases, the cabin air temperature reached the required (adjusted) value (23 C) in minutes [11].

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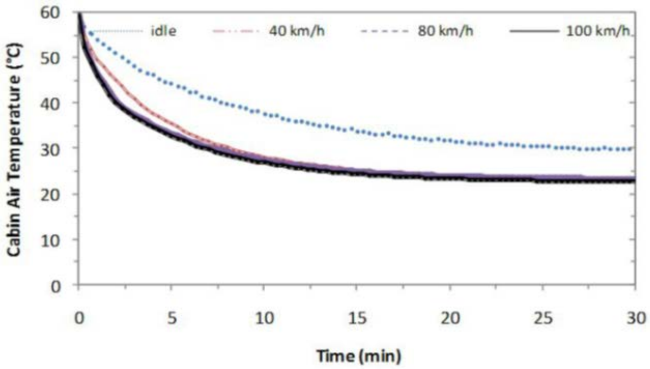

Fig. 4, Variation of cabin air temperature with time for various vehicle speeds [11].

3 Impact of Air Conditioning and Fuel Economy

Vehicle air conditioning loads are the most significant auxiliary loads present in vehicles today. The AC energy use for a typical 8.7l/100km vehicle is as shown in the figure below. An air conditioning compressor can add up to a 5-6kW peak power load on a vehicle's engine. The fuel economy of a vehicle drops significantly when the AC compressor load gets added to the engine. The effect is even larger in high fuel economy vehicles.

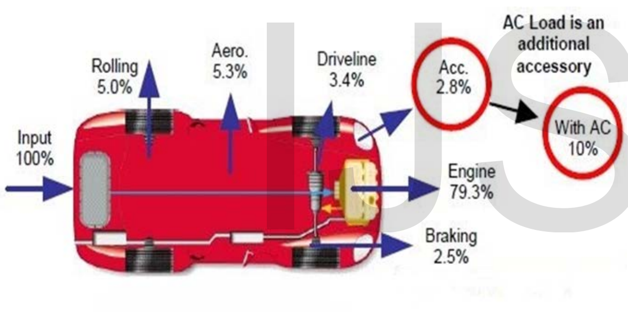

Fig. 5, Percent Vehicle Energy Uses in a Conventional Vehicle [1].

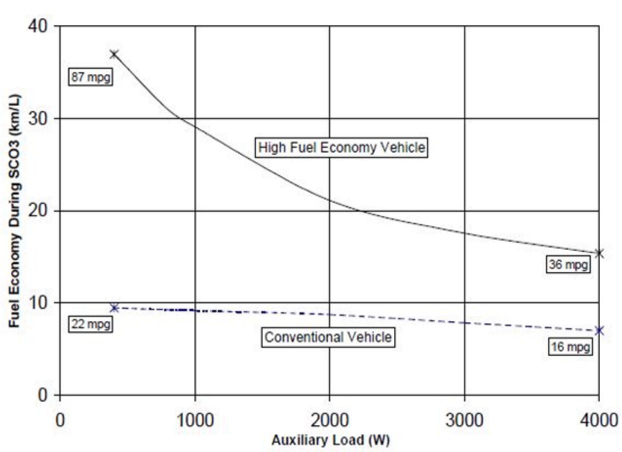

Fig. 6, Fuel Economy Impacts of Auxiliary Loads [2].

According to a study performed at the NREL, US, scientists found out the relation between auxiliary load and fuel economy, and the above graph shows the relation between auxiliary load on the engine and the fuel economy of a conventional and a high fuel economy vehicle. As seen in the graph there is a significant decrease in the fuel economy of a vehicle as the auxiliary load on the engine steadily increases from 0 to 4000 W.

A point worth noting here is that, though the extra fuel per kilometer consumed for the air conditioning process decreases from urban to highway driving, the estimated power consumed by the AC system increases sharply. Since the thermal load of the AC system does not increase, this highlights the inefficient operation of AC systems at higher engine speeds. Therefore, it may be assumed that most AC systems are designed to work well at idle and low rpm's (urban) but are inefficient at higher engine speeds (highway) [4]. In such a case, significant fuel savings could be achieved by using electrically powered compressors instead of mechanically powered compressors, which have an advantage of varying the compressor speed according to the cabin load instead of the engine speed. The use of electrically driven compressors results in significant fuel savings and maintenance cost.

4 Opportunities to Reduce Air Conditioning Load

The size of the air conditioning systems in cars is related to the peak thermal load in the vehicle. The peak load generally can be two to four times greater than the steady-state cooling load. The peak thermal load is generally related to the maximum temperature the cabin will reach while soaking in the sun. The thermal load can be further reduced by using more efficient distribution of the treated air as well as using more efficient equipment (such as by using waste heat to provide cooling) [2]. The peak load can be reduced by reducing the solar gain into the vehicle and by using ambient air to cool the hot vehicle cabin. Solar energy enters the vehicle and raises the cabin soak temperature through two paths: the windows and the opaque components of the vehicle, such as the roof. Therefore, the peak cabin soak temperature must be lowered to reduce the air-conditioning load on the engine. One common misconception is that insulating the cabin roof will reduce the cooling load in the cabin. Although this may be true in the steady-state mode, it may not be true when a typical vehicle is soaking in the sun. Insulating the roof can increase the cabin temperature as the cabin gains solar heat through the glass but can no longer reject it through the roof. Although it may seem intuitive to insulate the vehicle roof to reduce the solar gain, roof insulation can actually increase the cabin temperature, because the roof (particularly if it is light-colored) serves as a heat rejection path as the cabin temperature rises [2].

It was observed that during a typical Indian hot afternoon the ambient conditions can lead to surface temperatures of more than 103°C and cabin air temperatures higher than 61°C turning passenger cabins into virtual ovens. The Indian summers can be especially harsh, where the ambient temperature rises up to 50°C which leads to roof surface temperatures up to

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110°C and cabin temperature up to 74°C. The various methods to reduce this auxiliary air conditioning load on the engine are discussed below.

4.1 Thermal load reduction by-

Use of Advanced Window Glazing

The main function of Advanced Glazing's is simple, to keep the cabin environment cooler than the outside environment. Reducing the transmittance of the glazing can have a greater impact on the cabin soak temperature than ventilating the vehicle during a hot soak. That is why, Government should encourage the use of advanced glazings in modern automobiles. They are effective in reducing the transmission of solar radiation into the vehicle cabin. The thermal gains due to advanced glazings are typically lesser compared to conventional glazings. They reduce the solar gain in a significant manner, which can result in downsizing the compressor. This ultimately increases the fuel economy of the vehicle up to 5%. A recent study performed by R. Farrington and J. Rugh of the National Renewable Energy Laboratory (NREL) in United States revealed some startling results regarding the use of advanced window glazings.

They tested three windshields supplied by PPG: Solex, a standard windshield in the United States; Solar Green, a windshield used in European vehicles; and Sungate, an advanced ultraviolet and infrared reflecting windshield [2]. Advanced windshields, such as Sungate, effectively reduce the transmission of ultraviolet and infrared solar radiation into the vehicle compartment. Figure 7, compares the transmittance of the Sungate, windshield with that of a conventional windshield. The Sungate windshield uses a multi-layer silver coating deposited on the glass between the inner and outer glass of the windshield to reflect infrared radiation.

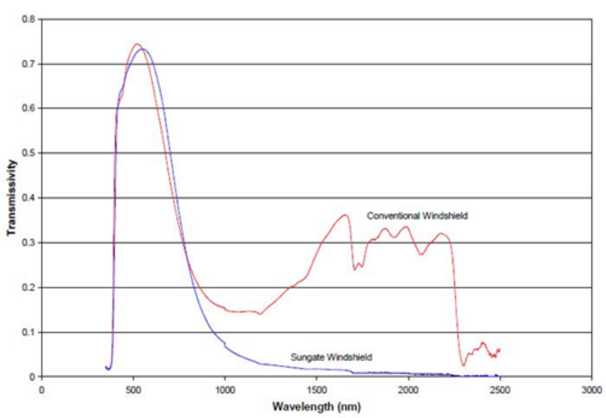

Fig. 7, Transmittance of Solar-Reflecting Windshield [2].

The Solex windshield had 17% more thermal gain than the Sungate windshield. The solar gains in the vehicle decreased by 27% when the standard front windshield (Solex) was replaced with the Sungate windshield [2].

Parked car ventilation

One of the major thermal loads acting on the passenger cabin is due to the solar radiation and this solar radiation fluctuates depending on the parking conditions. Parking condition is a factor of the amount of shade, availability of air flow, velocity of air flow, ambient conditions & parked duration. A car parked in natural shade will have relatively less cabin temperatures as compared to the same car parked in scorching sun. This has a significant effect on the thermal load acting on the passenger cabin.

4.2 Use of Seat based climate control

A standard car seat blocks your body's built in cooling system. Ordinarily one ejects heat through the pores in the form of water vapor, which carries the heat invisibly to the air. Having a seat pressed against your back and bottom prevents this water vapor, from escaping, causing it to condense into sticky sweat. But porous covering of an air conditioned seat allows your body's natural cooling system to work even when sitting down and keeps you cool by circulating air across your skin. The moving air carries away your body's heat. By the use of heated/cooled seats in light motor vehicles which confines the cooled air directly to the spot where the hot passenger is sitting, seat based climate control can be achieved.

The fabric of such a car seat is a porous mesh, so air can flow through it. Multiple fans inside the seat produce air circulation, which blows through diffusion layer that spreads the cooling effect throughout the seat and outward through the mesh, cooling the surface. This air may or may not be refrigerated. In air conditioned seats which produce refrigerated air, a small cooling element is used, which unlike other air conditioners also works on vapor compression cycle. Such seats have some important advantages over the conventional seats.
Because the space being cooled is limited to a single seat, relatively little energy is required compared with normal air conditioning. Air conditioned seats use energy more efficiently than the conventional air conditioners that cool the entire interior of the car. They don't completely eliminate fuel use and pollution but they minimize it.

4.3 Use of recirculated Air

The next most important technique to minimizing air conditioning loads is to reduce the amount of outside air brought in for ventilation. Since it is more effective to condition the recirculated cabin air than to treat very cold or very hot air from outside [2]. Fig. 8 illustrates the modeled benefits of using recirculated air. As the percentage of recirculated air is increased, the amount of heating or cooling thermal power required is reduced. With increasing the air circulation ratio, the cabin air temperature decreases faster than that when more fresh atmospheric enters the cabin (lower circulation ratio) during a specific operating time period.

The thermal power required is a function of the ambient temperature, air flow rate, percent recirculated air, humidity, and

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the heat gain/loss of the passenger compartment [10].

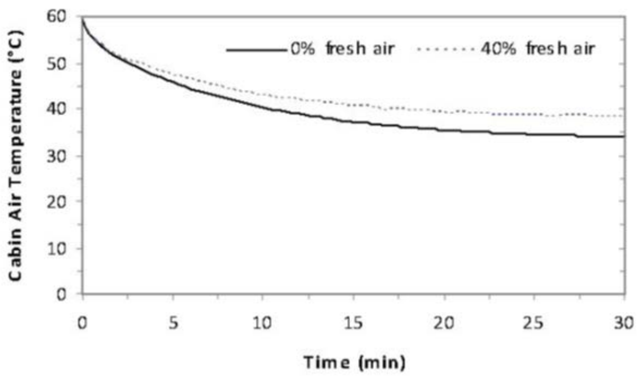

Fig. 8, Variation of cabin air temperature at two conditions: 0% and 40% fresh air [11].

4.4 Application of Alternative Cabin Cooling techniques

The present trend of a steady increase in the population is causing rapid depletion in the reserves of fossil fuels due to increase in energy consumption. But even today, we are not able to utilize all the heat given by the fuels. Thus, there is urgent need of a system is able to recover waste heat at low temperature levels, which can be interesting alternative for energy conservation. The concept of automobile waste heat driven cooling seems to be very attractive and wide studies have already been conducted on it. In movable engines, different cooling techniques can be used. But adsorption chillers are more felicitous because the system is simple and there are no moving parts. In automobiles which run at extremely high speeds, adsorption operated air conditioning is the appropriate solution as this is suitable for vibration inclined and rotation occasions.

An adsorption refrigeration system is similar to vapor compression system except that heat instead of work provides the energy needed for compression. Unlike conventional vapor compression system which require a mechanical compressor assembly, this new technology uses a thermally driven static sorption bed, saving as much as 90% of the required input power, typically used to drive a mechanical compressor.
Use of alternative cabin techniques will cause:

a) Increase in the fuel economy of a vehicle which will result in significant amount in fuel savings.
b) Less wear and tear of the engine.
c) Reduction in environmental pollution due to lesser fuel consumption.
d) Increased engine performance.

5 CONCLUSION

Current air conditioning systems reduces the fuel economy of a conventional vehicle by at least 1.52 km per liter , and has an unacceptable impact on high fuel economy vehicle where the mileage was found to be reduced by 2.54 km per liter. Therefore reduction in the air conditioning load can have a significant benefit especially because of the large number of new cars sold each year. Air conditioning systems also cause extra CO_2 emissions in and thus fuel consumptions that increase significantly with temperature & solar irradiation. And as previously mentioned the ways to reduce the amount of energy spent for cabin environment control are multiple and include optimization of peak cabin soak temperatures, parked car ventilation, use of heated/cooled seats, recirculated air, alternative cabin cooling techniques and advanced glazing's which will assist in decreasing the air conditioning load on the engine. Therefore, reductions in automotive air conditioning loads on the engine are quite clearly the need of the hour, making tomorrow's vehicles more fuel efficient, while keeping passengers comfortable.

In a country like India where fleet penetration has reached high level, we can save substantial amount in foreign exchange & reduce the dependence on crude oil imports & reduce the extra atmospheric pollution caused due to the use of automobile air conditioning systems.

Therefore, Reductions in automotive air conditioning loads on the engine are quite clearly the need of the hour, making tomorrow's vehicles more fuel efficient, while keeping passengers comfortable.

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