

# New Trends in the Field of Automobile Air Conditioning

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## Abstract

This article presents new trends in the area of automobile air conditioning, which is fast becoming standard equipment. Attention is focused on the refrigerant and ventilation circuit of the air conditioning equipment, and on the control system. An analysis is presented here of a commonly used contemporary refrigeration system working with the refrigerant R134a and a promising transcritical refrigeration system using CO<sub>2</sub> as a refrigerant. The article also deals with the configuration of some components of a transcritical refrigeration system. Additionally, attention is paid to physiologically controlled air conditioning and multizone air conditioning systems which make it possible for every individual in the automobile cabin to have an optimum microclimate.

**Key words:** air conditioning, automobile, refrigerant circuit, ventilation circuit, control system.

## 1. Introduction

Automobile air conditioning has become more and more commonplace. The air conditioning system ensures a thermal comfort for passengers, but also contributes to the defogging of windows and thus increases the active safety factor. Automobile air conditioning equipment is markedly different from the air conditioning facilities found in buildings since, in contrast to the stable conditions of a building, conditions inside an automobile vary markedly in both time and space.

Among the most significant new trends in automobile air conditioning is the use of alternative refrigerants to replace the more usual R134a, the use of physiologically controlled air conditioning, and multizone air conditioning systems. Because of its contribution to the greenhouse effect, the long-term prospects for R134a, which has been used to the present time, are not very good. The best candidate to replace R134a as a refrigerant in automobile air conditioning is CO<sub>2</sub>. The refrigeration cycle functioning under CO<sub>2</sub> is transcritical and, due to the working pressures in the refrigeration system, some components require special configuration.

At the present time, the majority of fully automatic air conditioning equipment used in automobiles regulates themselves based upon temperature measurements in the area near the driver. Evolution is toward so-called physiologically controlled air conditioning, in which an optimum thermal microclimate is reached by means of several sets of sensors which measure the thermal state in the automobile cabin. This form of regulation also includes a sensor to measure pollution in the outside environment. Also among these new trends are systems

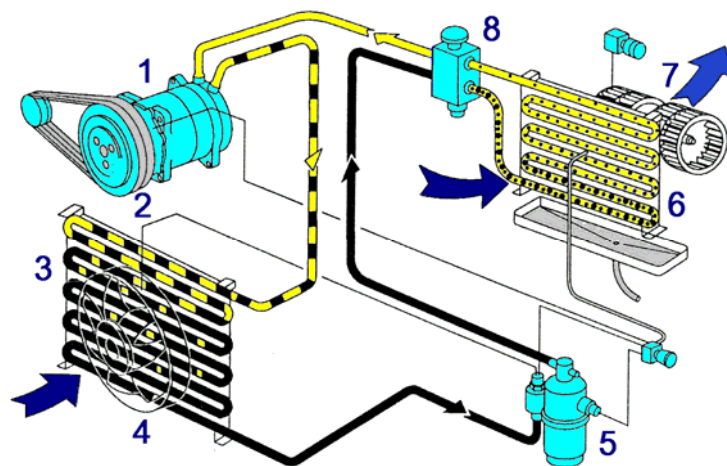
which make it possible to climatize the cabin using several zones, thus creating an optimal microclimate for every passenger, at both the head and foot level.

The automobile air conditioning system consists of the refrigerant and ventilation circuit, and a system of control.

## 2. The Refrigerant Circuit in the Automobile Air Conditioning

The basic components of the refrigerant circuit are the compressor, the condenser, the refrigerant cartridge with safety device and drying pad, the expansion valve and the evaporator (Fig. 1).

The compressor must ensure that vapor of the refrigerant is removed from the evaporator in such a way as to ensure that both pressure and temperature are maintained at required levels. At the same time, circulation of the refrigerant must be maintained in the cooling circuit. Given that the compressor is run by the engine of the vehicle, it must operate with wide variation in rotating speeds, which will impact the refrigerant equipment capacity. Modern compressors with variable capacity allow transport quantities to vary between 0 and 100% and thereby lessen fuel demands.



*Fig. 1 Refrigerant circuit in the automobile 1-compressor, 2-electromagnetic coupler, 3-condenser, 4-accessory fan, 5-refrigerant cartridge with safety device and drying pad, 6-evaporator, 7-evaporator fan, 8-expansion valve*

The condenser is cooled either using ram air effect or a stream of air induced by a fan.

The liquid refrigerant cartridge serves as both an equalizing and reserve unit. The amount of refrigerant that will be required at any one time within the refrigeration cycle is dependent upon operating conditions. The drying pad may absorb out of the refrigerant any water or impurities which may occur. The safety device turns on the condenser's accessory fan in the event there is excessive refrigerant temperature and switches it off in cases of excess exit pressure or when entry pressure falls below allowable levels.

The expansion valve lowers the pressure of the liquid refrigerant and limits its flow so that the evaporator will be able to completely evaporate it. A thermostatic expansion valve (TXV), or

capillary tube, is most often used. A separator to separate refrigerant vapor from the liquid and get rid of moisture and dirt is necessary for the TXV to function. An accumulator is located in the capillary tube circuit behind the evaporator which serves to catch liquid refrigerant which may exit the evaporator in some cases and could harm the compressor. As with the separator, the accumulator also serves to catch moisture and dirt.

### 3. The Ventilation Circuit in the Automobile Air Conditioning

Three distinct operational states can be discerned in the ventilation circuit (Fig. 2) – the open circuit, the closed circuit and the partially closed circuit.

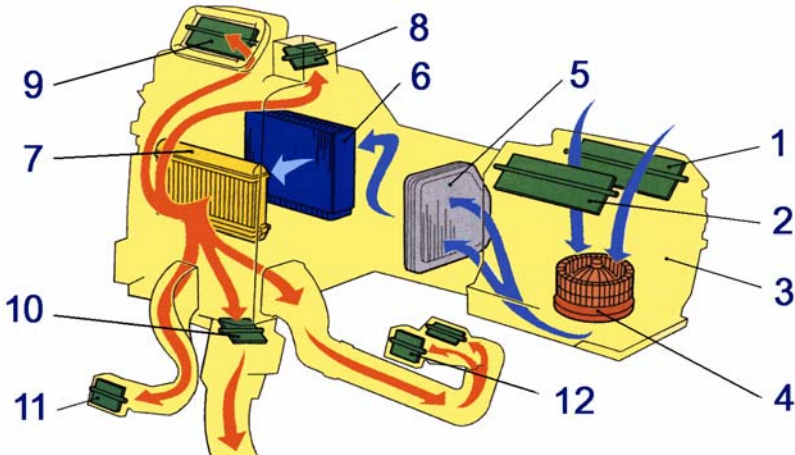


Fig. 2 Air distribution in the automobile air conditioning. 1-fresh air valve, 2-internal circulation valve, 3-air mixing chamber, 4-ventilator, 5-air filter, 6-evaporator, 7-heater, 8-windshield defroster outlets valve, 9-central duct valve, 10-leg outlet valve, 11-anterior outlet valve, 12-side outlet valve

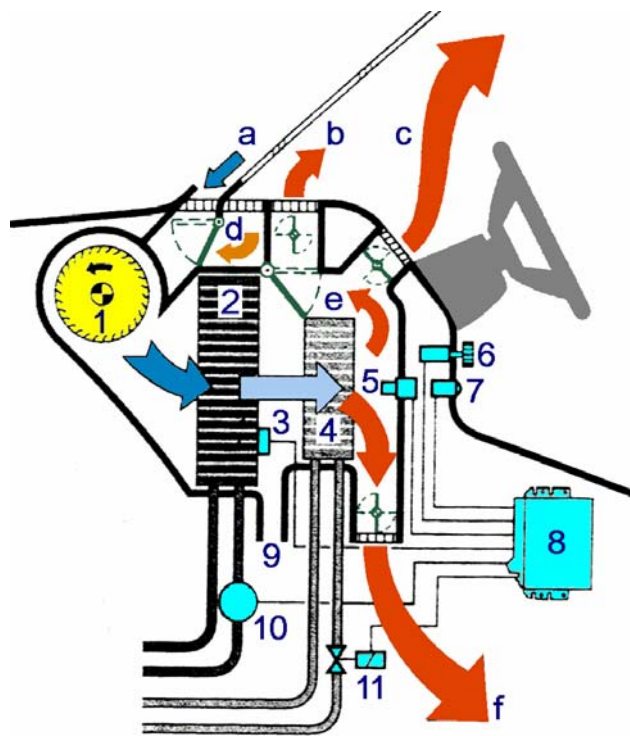
The fresh air valve controls regulation of air intake in an open circuit. From here, it flows through the air filter into the evaporator, where it cools and the moisture is condensed out. The air is then warmed in the heat exchanger to the appropriate temperature and is led via the distribution valves and outlets to the required places in the interior environment of the vehicle. In a closed circuit, air intake is primarily from the internal environment of the vehicle, while in a partially closed circuit, a mixture of internal and outside air is used.

### 4. Air Conditioning Control Systems

Control system of the air conditioning equipment ensures the desired temperature of the inner cabin air, and controls the amount of air intake as well as its distribution. In manually controlled systems, the desired air temperature, distribution and air intake level are set using the appropriate manual controls. In temperature controlled systems, the chosen temperature is automatically maintained, while air distribution and air intake are controlled manually.

Fully automatic control with programmable selection independently ensures the desired internal air temperature, air intake amount and air distribution. The desired temperature is maintained using either an air régime or water régime (Fig. 3). Fresh air drawn in by the fan (1) is either cooled in the evaporator (2) or warmed in the heater (4) to the desired

temperature and then, depending upon the position of the valves, is moved into individual areas within the internal environment of the automobile (b, c, f). The electronic control unit (8) registers the temperatures as indicated by the sensors (3, 5, 7) and the temperature to which the selector (6) is set. The desired temperature is compared to the actual temperature and the difference is converted in the control unit into regulation variables for heating (4, 11) and cooling (2, 10) capacity, managing the amount of air (1), and regulating air distribution (by the position of valves b, c, d, e, f), depending upon the program choices made by passengers.



- a fresh air
- b windshield outlet
- c upper outlet
- d internal circulation
- e bypass
- f lower outlet

*Fig. 3 Automatic control of automobile air conditioning.*

*1-fan, 2-evaporator, 3-evaporator temperature sensor, 4-heater, 5-exhaust air temperature sensor, 6-temperature selector, 7-internal temperature sensor, 8-electronic control unit, 9-condensed water drain, 10-compressor, 11-electromagnetic valve*

At higher driving speeds, the dynamic pressure of air transported by the fan increases, as does the amount of air transferred. In this case, with increasing speed this specialized device first lowers the fan's revolutions, if necessary to the zero level, and if that is insufficient, limits air intake with a throttle valve so that constant rate of flow is maintained.

Setting a defrost régime enables frosted or fogged windows to be cleared as soon as possible. When temperatures are above 0 °C, the refrigeration system is used to provide for dry air.

Most fully automatic air conditioning systems function solely on the basis of the temperature measured in the area around the driver. A new trend is so-called physiologically controlled air conditioning, which achieves an optimal microclimate using additional variables. The core piece of such an air conditioning system is outfitted with a large number of sensors which continuously measure temperature, speed and humidity of air during the journey, along with heat flow generated by the sun. From this information, the system calculates and automatically selects the optimal temperature settings. The system can also ensure ideal relative humidity in the automobile cabin (around 40%). This is achieved by regulating temperature in the evaporator, upon which the degree of dehumidification depends. Apart from this, physiologically regulated air conditioning uses external pollution sensors. Circulation is switched from external to internal depending upon measured concentrations of nitrogen oxide and carbon mono oxide.

Currently, most automatic air conditioning systems are single-zone, i.e., adjustments made to airflow into the cabin are unilateral. The latest air conditioning systems make it possible to control climate in several zones (usually four). A microchip maintains temperature settings for individual passenger positions. It is responsible for regulating, metering out and adjusting the air temperature via a servo motor which creates varying air streams. A unique microclimate may be created for each individual in the passenger compartment of the automobile, with optimal temperature air distribution between head and feet. In some automobiles, four climate zones can be achieved by installing separate air conditioning facilities for front and rear seat passengers.

## 5. Analysis of Air Conditioning Systems Operating with CO<sub>2</sub> and R134a

Automobile air conditioning systems presently use the refrigerant R134a. Because of its contribution to the greenhouse effect, which is 1300 times that of CO<sub>2</sub>, its long-term prospects are not good. Intensive research and development is underway into refrigeration systems using alternative refrigerants (Joudi et al 2003). CO<sub>2</sub> is among the alternative refrigerants used for automobile air conditioning.

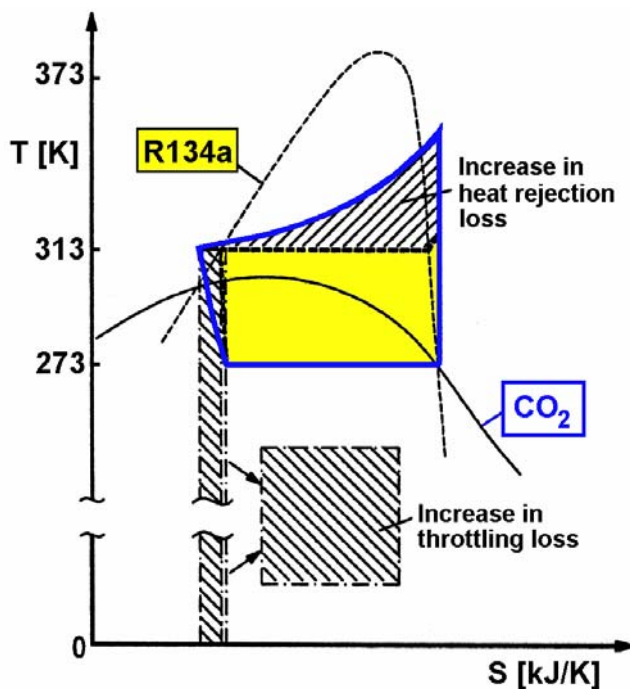


Fig. 4 Comparison of thermodynamic cycles for CO<sub>2</sub> and R134a

CO<sub>2</sub> refrigeration system functions in air conditioning equipments right at the critical pressure of 7.38 MPa, or sometimes above it (Kim et al 2004). Heat transfer therefore takes place in many cases at supercritical temperatures and the cycle is transcritical, i.e., it has a subcritical low-pressure side and a supercritical high-pressure side. At supercritical pressures, saturation conditions do not exist and pressure is independent of temperature.

For a given evaporation temperature and minimum heat rejection temperature on exit from the cooler, a transcritical cycle has greater thermodynamic loss than a condensation cycle (Fig. 4). As a consequence of the higher median temperature of heat rejection in the CO<sub>2</sub> cooler and the greater heat loss

due to throttling, the theoretical cycle work for CO<sub>2</sub> increases compared to a conventional refrigerant like R134a. The use of two-stage compression and a cycle with subcooling liquid refrigerant in the internal heat exchanger leads to improved capacity and coefficient of performance (COP) and a reduced size for the refrigeration equipment components, and also prevents wet vapor from entering the throttling valve. The refrigerant is subcooled by vapors

exiting the evaporator which are thus overheated, preventing the compressor from taking on wet vapor.

## 6. Draft for a CO<sub>2</sub> component system

In CO<sub>2</sub> systems, the compressor works under high median effective pressure and the pressure ratio (discharge pressure to suction pressure) is relatively low. The pressure ratio to deliver identical refrigerating capacity is 3.1 using CO<sub>2</sub> and 5 using R134a. The compressor becomes more efficient as the pressure ratio tends lower. For the transcritical cycle, the compressor requires thicker walls, but it is still smaller than a compressor which delivers the same capacity using R134a as a refrigerant. Piston and rotary compressors (rotary vane, rolling pistons, scroll) both single- and two-stage, are being developed for CO<sub>2</sub> refrigeration systems.

The use of two-stage compressors improves COP by up to 20%.

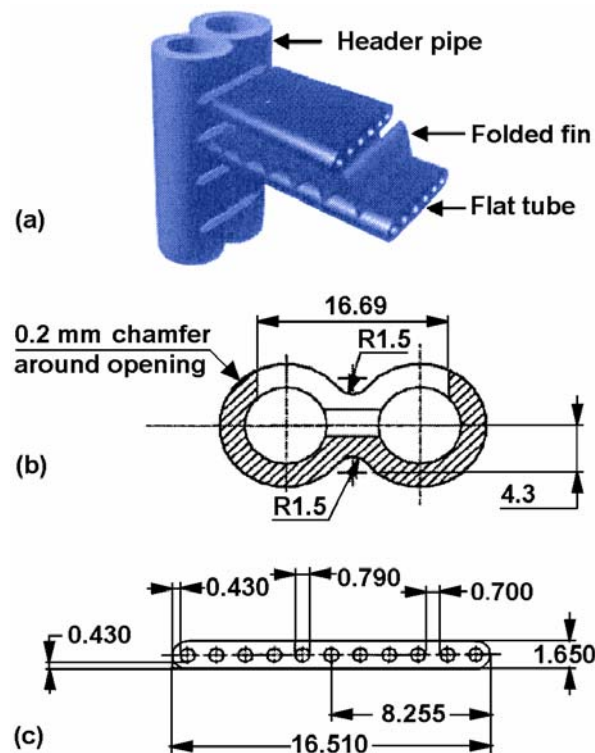


Fig. 5 Microchannel CO<sub>2</sub> gas cooler.

- (a) Cooler geometry
- (b) Cross-section of header pipe
- (c) Flat microchannel tube.

A CO<sub>2</sub> gas cooler has better heat transfer as a result of greater convection heat transfer in the vicinity of the critical point and as a result of the high pressure, which allows for higher velocities of refrigerant flow. Because of the high pressures, a cooler with flat microchannel tubes is used, fitted with folded louvered fins as we can see in Fig. 5 (Pettersen et al 1998).

The internal heat exchanger, in which the refrigerant exiting the cooler is subcooled by vapors exiting the evaporator, can increase the efficiency of the cooling cycle working under CO<sub>2</sub> by up to 25%. An example of microchannel configurations for the internal heat exchanger is given in Fig. 6 (Kim et al 2004). These configurations, in comparison with the conventional concentric tube designs, reduce demands on the material by 50% and increasing effectiveness by 10%.

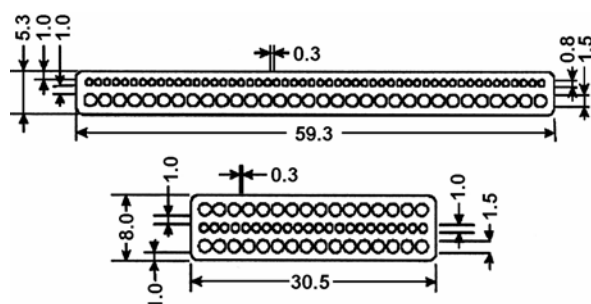


Fig. 6 Microchannel configurations of the internal heat exchanger

## 7. Concluding Remarks

The analysis offered here of automobile air conditioning systems working with the refrigerant R134a and more promising transcritical systems using CO<sub>2</sub> demonstrates that CO<sub>2</sub> technology brings with it many advantages. As an example, when refrigeration systems work with

CO<sub>2</sub> and R134a and with heat exchangers of identical proportions, system using CO<sub>2</sub> will have greater refrigerating capacity and allow lower cabin temperatures to be achieved in the automobile at the same time it cuts fuel demands by 25 to 30%. Some components of refrigeration systems working under CO<sub>2</sub>, however, require fresh configuration. Modern physiologically controlled air conditioning makes possible the automatic control not only of temperature in the automobile cabin, but also humidity and velocity of air, and permits automatic switching between external and internal air circulation. With multizone automatic air conditioning systems, it becomes possible to create an optimal microclimate for each individual in the passenger compartment of the automobile.

## **Acknowledgements**

The authors gratefully acknowledge the financial support of the Ministry of Education of the Czech Republic in implementing the research plan MSM262100001.

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