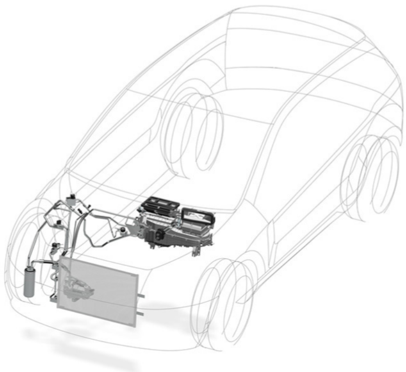
Development of Heat Pump System for xEVs



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In recent years, xEVs (including BEVs, HEVs, PHEVs, and FCEVs) have rapidly spread across the globe in an effort to meet stricter environmental regulations. Under such circumstances, it is required to reduce the amount of power used for air conditioning, which directly affects their driving range. For the heat pump systems of xEVs that can reduce the power consumption of air conditioning in winter, we made computational models of the air conditioning cycle and its control system, and through simulation studied the control of heat pump systems to achieve both power saving and thermal comfort.Subsequently, we also confirmed that both high efficiency and thermal comfort can be achieved by controlling the components of the heat pump system properly with vehicle test.

1. Introduction

In response to the global strengthening of environmental protection (suppression of global warming gas emissions) and the accompanying vehicle fuel efficiency regulations, xEVs such as battery electric vehicles and hybrid electric vehicles, have been rapidly spreading. In the case of xEVs, the electric power used for air conditioning directly affects the range of battery-powered driving, so demand for energy saving in air conditioning is growing. In particular, heat pump systems that can reduce the power used for air conditioning, during heating in winter are effective technologies for extending the driving range, and are expected to be widely adopted in the future.

However, the realization of the functions essential for ensuring passenger safety, which are unique to automotive air conditioning, is also necessary when adopting heat pump systems. Therefore, to achieve both air conditioning power saving and passenger safety and comfort, Mitsubishi Heavy Industries Thermal Systems, Ltd. used control simulation software as a system development tool that controls equipment such as an HVAC (Heating, Ventilation and Air Conditioning) unit, solenoid valves, and electronic expansion valves (EXVs) that constitute heat pump systems for xEVs in an integrated manner. We also carried out modeling on a computer, examined the optimization of the system control through simulation and implemented verification using an actual vehicle.

2. Control of heat pump system for xEV

Power saving of heat pump systems for xEVs and ensuring passenger safety and comfort can be realized simultaneously by controlling the components of the air conditioning system including the HVAC unit, electric compressor, solenoid valves and EXV appropriately, based on the ambient temperature, temperature setting and temperature and pressure information of the air conditioning system obtained from the sensors. To achieve the above, a heat pump system model and its control logic were programmed into a computer and were used for various preliminary verifications. As a

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result, practical heat pump control was established without requiring a large amount of experimental cost and time.

Controlled objects include the electric compressor, HVAC unit, solenoid valves, EXV and cooling fan. **Figure 1** shows the control schematic diagram. The HVAC unit (blower speed, outlet mode, outlet air temperature control and air inlet mode) and refrigerant circuit (electric compressor speed, solenoid valve operation and EXV opening area) are controlled by the ECU (Electronic Control Unit) based on air conditioning setting information, vehicle sensor information and air conditioning system sensor information. The power saving was evaluated with the ECU, HVAC unit and refrigerant circuit. The air conditioning function was evaluated with entire the system including the vehicle.

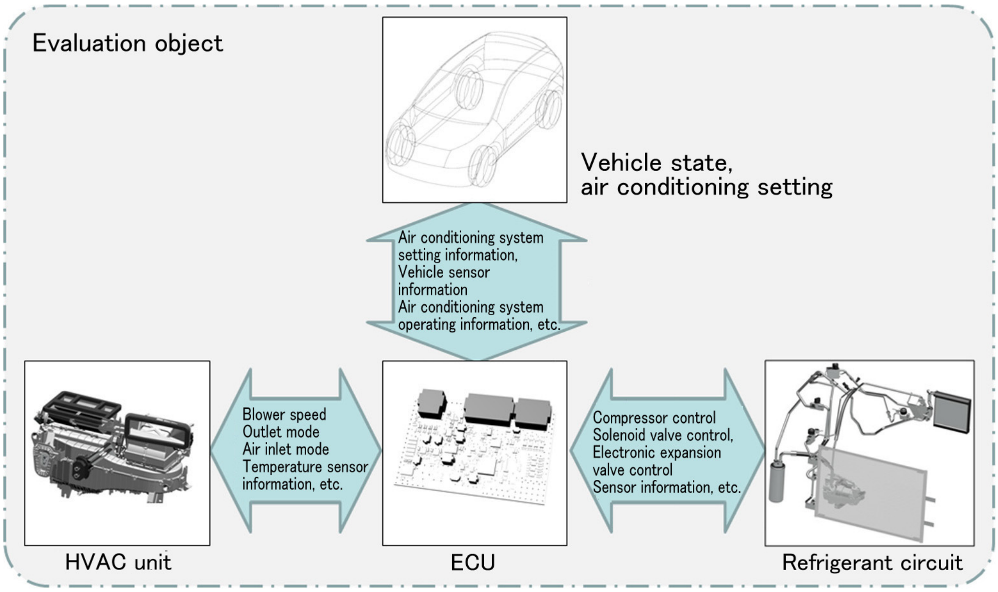

Figure 1　Control of vehicle heat pump system

Figure 2 shows a specific example of the control logic on a computer. The HVAC unit control logic controls the outlet mode, outlet air temperature, air flow rate and air inlet mode, etc., and refrigerant circuit control logic controls electric compressor speed, solenoid valve operation, EXV opening area and cooling fan speed, etc.. This report shows the result of confirming the system operating state by performing various verifications on the EXV control as an example. After full verification of the validity of the control logic and control parameters on a computer, the operation states were confirmed with an actual vehicle.

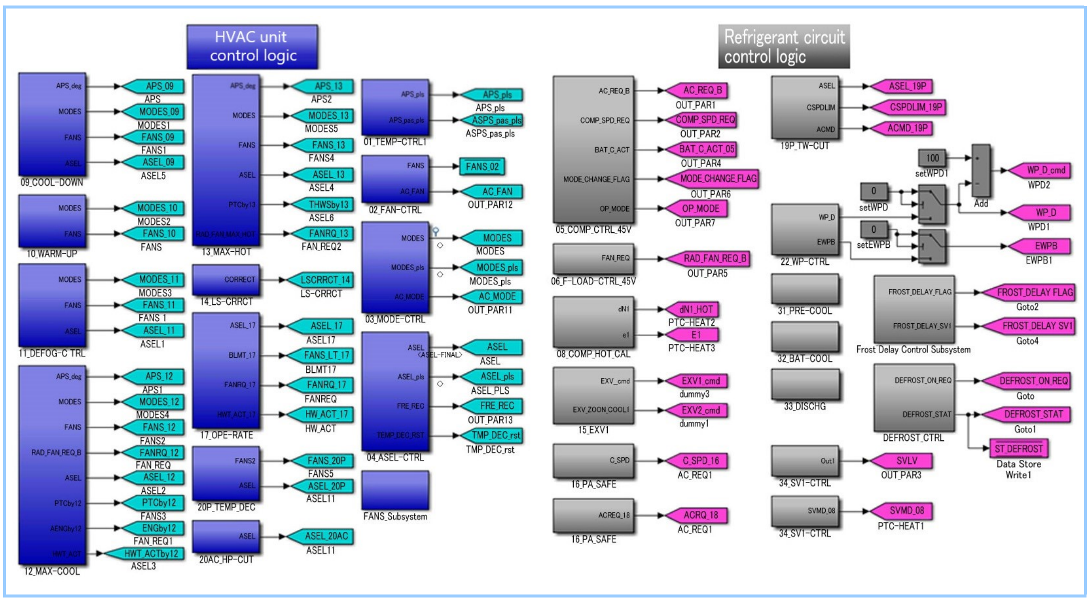

Figure 2　Control logic

3. Power saving

To save power, it is important to control the refrigerant circuit appropriately. This section describes the approach to power saving with electric compressor speed control and the EXV opening area control that greatly affect air conditioning performance.

To select control parameters which are assumed to be correlated to air conditioning performance and to be able to acquire temperature and pressure information via each sensor in the refrigerant circuit, the air conditioning performance coefficient (COP) and outlet air temperature were obtained with various compressor speeds and EXV opening areas through experiments. The evaluation was carried out under the three electric compressor speed conditions of low, medium and high with a constant ambient temperature, cooling fan speed, HVAC outlet mode and airflow rate. **Figure 3** (a) presents changes in the COP and outlet air temperature in response to the EXV opening area during heating operation as an example. Since the EXV opening area at which the COP and the outlet air temperature are maximized differs for each compressor speed, the experimental results were rearranged using control parameters A and B. The results are shown in Figure 3 (b) and (c). In the case of control parameter A, the control parameter that maximizes the COP regardless of whether the electric compressor speed is low, medium or high exists in a relatively wide range. On the other hand, in the case of control parameter B, the range in which the COP is maximized is limited and varies depending on the electric compressor speed. In both cases of control parameter A and B, the outlet air temperature tends to increase as the parameter value increases.

From the above, it can be seen that EXV control using an appropriate control parameter is necessary to achieve both power saving and the specified air conditioning performance.

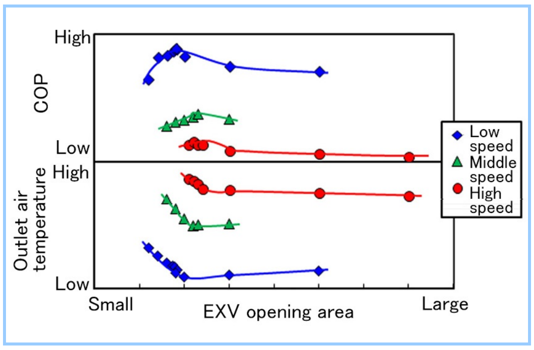

Figure 3 (a) Changes in COP and outlet air temperature depending on EXV opening area

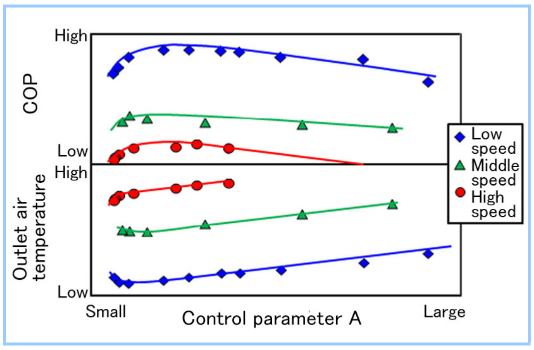

Figure 3 (b) Relationship between control parameter and COP, outlet air temperature in the case of control parameter A

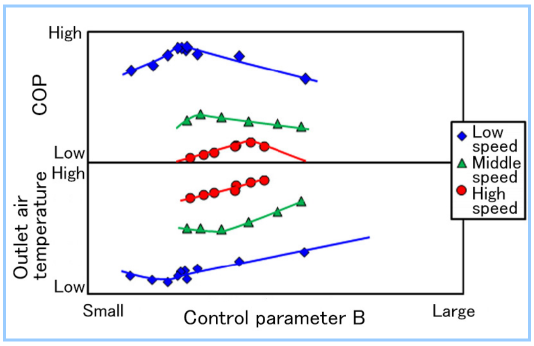

Figure 3 (c) Relationship between control parameter and COP, outlet air temperature in the case of control parameter B

4. Dehumidification heating

One of the necessary functions of heat pump systems for xEVs is dehumidification heating. This function dehumidifies the outlet air with an evaporator before heating the air in the HVAC unit under a certain ambient temperature range to prevent the inside of vehicle windows from fogging. For dehumidification heating, air is cooled and dehumidified while passing through the evaporator in the HVAC unit, and then reheated while passing through the heater, and relatively hot air is blown into the vehicle cabin.

Since the required amounts of dehumidification and reheating vary depending on the ambient temperature and temperature setting, it is necessary to control the evaporation temperature and refrigerant flow rate by controlling EXV opening areas, as well as the electric compressor speed. We established refrigerant circuit characteristics and multiple control logic plans on a computer in advance, performed simulations, examined the feasibility of the dehumidification heating function and confirmed the effect.

Figure 4 gives a typical example of the simulation results. The air conditioning operation was set to “Auto” with a constant ambient temperature and vehicle speed. This shows the transition of the “Foot” outlet air temperature, the representative temperature in the vehicle cabin and the outlet temperature of the evaporator in the HVAC unit. In the case of control plan I, the outlet temperature of the evaporator in the HVAC unit was lower than the ambient temperature. This means that the dehumidification function worked, and the outlet air temperature was stable. On the other hand, in the case of control plan II, dehumidification functioned, but the outlet air temperature was unstable.

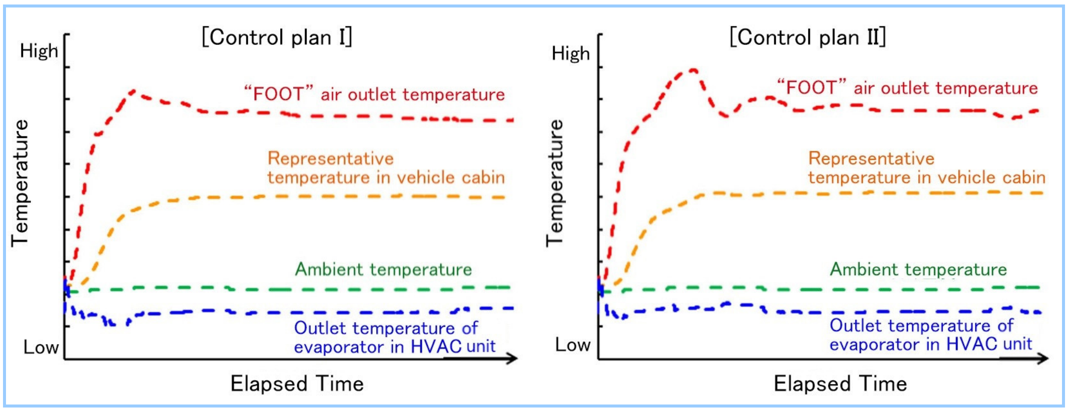

Figure 4 Simulation results of control plans I and II

We verified the controllability of control plan I (which had been confirmed by the simulation to have better controllability) with an actual vehicle test. The verification results are given in **Figure 5**. The vehicle test conditions were the same as the simulation conditions. It was verified that the dehumidification heating function worked, and outlet the air temperature was stably controlled. The vehicle test results were consistent with the simulation results.

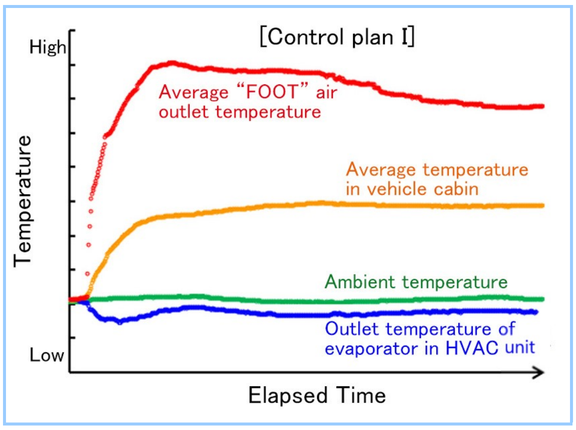

Figure 5 Results of dehumidification heating test of control plan I with actual vehicle

In addition, to confirm the controllability of control plan I under a wide range of operating conditions, the ambient temperature and the temperature setting were changed with the air conditioning operation set to “Auto.” The results are presented in **Figure 6**. Even when the temperature setting was raised or lowered under different ambient temperature conditions, the average temperature in the vehicle cabin followed the temperature setting and satisfactory air conditioning controllability was obtained.

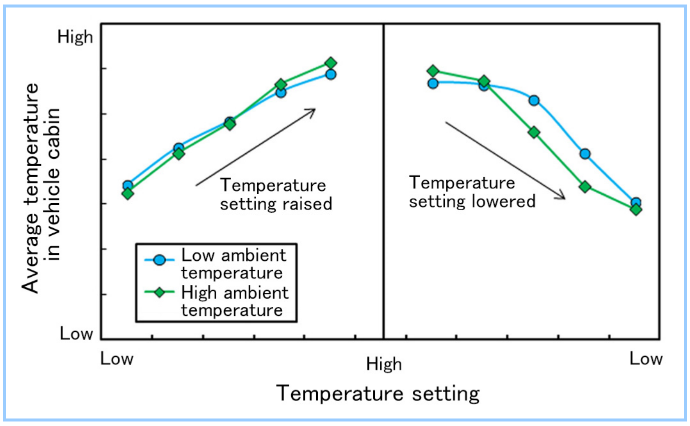

Figure 6 Controllability under conditions where temperature setting was changed

5. Conclusion

To achieve both air conditioning power saving and passenger safety and comfort, we used control simulation software as a system development tool that controls the components of a heat pump system for xEVs. Preliminary verifications were performed with this tool, and actual vehicle testing was implemented as an experimental verification.

In the development of a heat pump system for xEVs, higher efficiency and a dehumidification heating function were realized by appropriately setting and controlling the parameters that control the electric compressor speed, EXV opening area and HVAC unit.

We will proceed with the development of systems targeting not only higher efficiency and thermal comfort, but also a larger heating capacity for cold regions, and contribute to the progress of achieving a sustainable society by improving the marketability of the heat pump systems for xEVs and reducing power consumption to suppress carbon dioxide emissions.

References

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