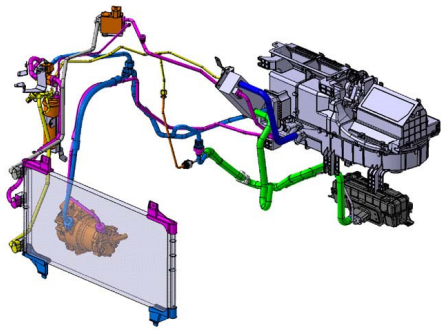
Development of Heat Pump System for Plug-in Hybrid Vehicles



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The product competitiveness of plug-in hybrid vehicles would increase dramatically if the driving mileage corresponding solely to the initial battery charge without starting the engine –Electric Vehicles (EV) driving mileage – increased. On the other hand, in terms of comfort, as the heating while the engine is off relies on electric water heaters, there are some disadvantages including increased power consumption as well as decreased EV driving mileage. This paper introduces the power-saving heat pump system which is used as a heat source for the water heater.

1. Introduction

As a heat source for air-conditioning systems used in electric vehicles (EVs) and hybrid vehicles (HEVs and PHEVs), Mitsubishi Heavy Industries Automotive Thermal Systems Co., Ltd. (MHI) currently mass-produces a system equipped with an electric water heater, which has been well-received by our customers. The advantages of this system include the fact that the necessary vehicle design changes could be kept to a minimum as the system is commonly used as the cabin unit in engine-driven vehicles. We developed a new "heat pump water heating system" in an attempt to increase the level of comfort, power-saving performance and development efficiency while fully utilizing the advantages of the existing system.

2. System overview

2.1 Heat pump water heating system

This system consists of an electric compressor, a water-cooling condenser, an outside heat exchanger, a receiver, an expansion valve, an inside evaporator and multiple solenoid valves for system switchover. The special features of this system include that the same cabin unit can be used for engine-driven vehicles as well.

The existing system structure and the new system structure are shown in **Figures 1** and **2**, respectively.

2.2 Electric power consumption for heating

Figure 3 shows a comparison of the power consumption for heating between the existing water heater system and the new heat pump water heating system. The test is based on simulated driving conditions in both cases.

Due to the effect of a heat pump system which utilizes the thermal energy in the outside air to heat the cabin, it was confirmed that the power consumption was successfully reduced by approximately 40%.

2.3 Heating startup performance

The chart shown in **Figure 4** indicates a comparison of heating startup performance, which ensures a certain level of comfort. According to the chart, it was confirmed that the average cabin temperature and the temperature of the air supplied from the heating outlet were almost the same. Since a level of comfort and power-saving performance have both been sufficiently achieved, the product competitiveness of the system itself is expected to increase further.

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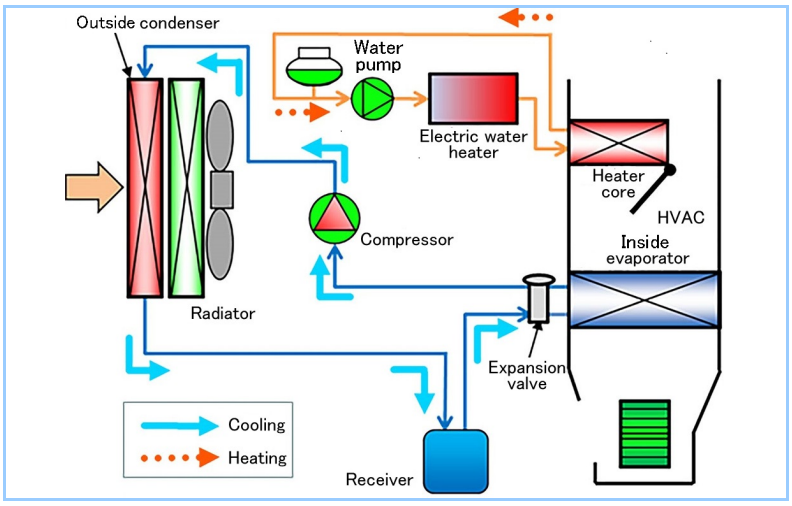

Figure 1 Structure of existing system

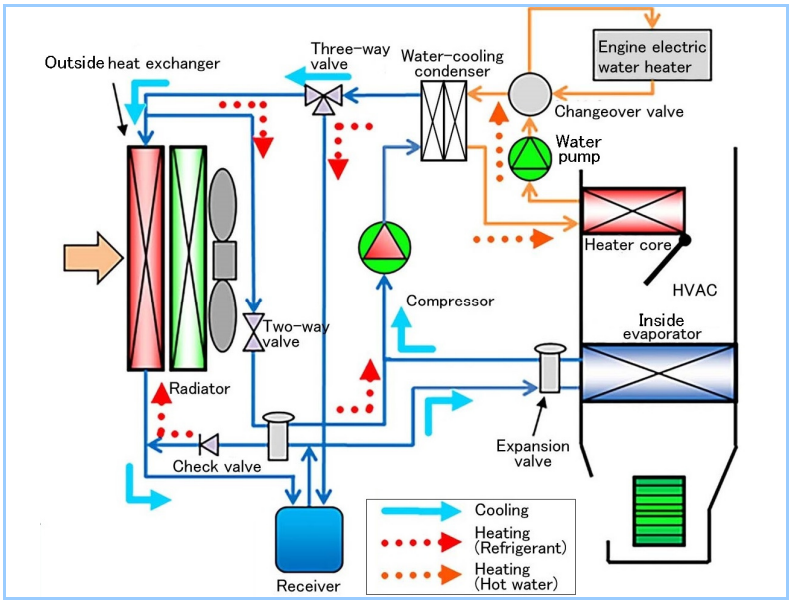

Figure 2 Structure of heat pump water heating system

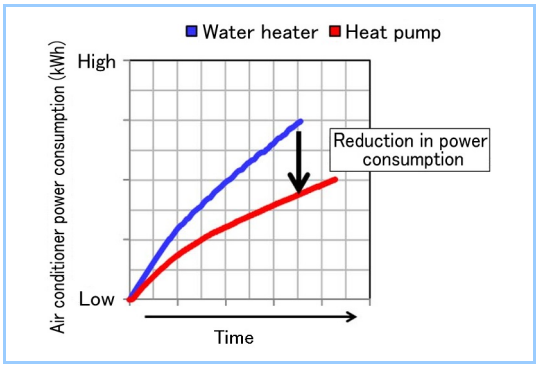

Figure 3 Comparison of power consumption for heating

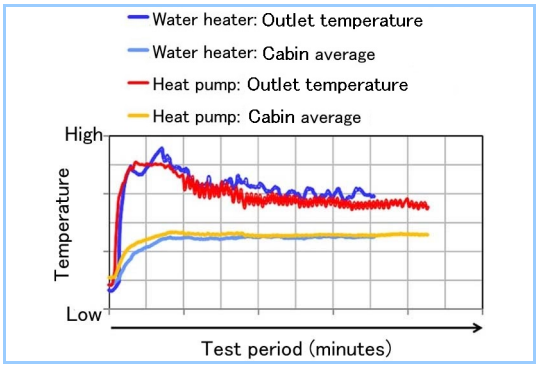

Figure 4 Comparison of start-up heating performance

3. Further performance improvement

In order to further improve the efficiency and the level of comfort in a low-temperature environment, the performance of the individual components has also been enhanced. The major components are introduced as follows.

3.1 Electric compressor

Increasing the efficiency of the electric compressor is the most important issue for the power-saving heating system. Furthermore, from the aspect of utilizing the same outline used in engine-driven vehicles, making the compressor as small as possible is also extremely important. The electric compressor adopted in this system has achieved the highest level of efficiency and

smallest size in the industry due to the structural review and upgrade of the conventional model, in addition to the introduction of new technologies. (**Figures 5** and **6**)

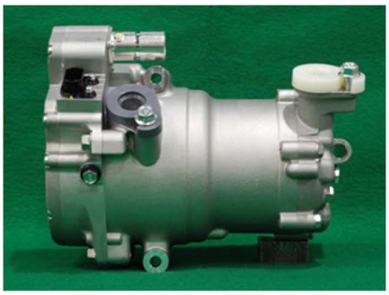

Figure 5 Next-generation electric compressor

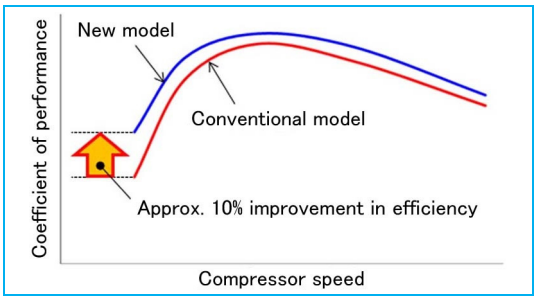

Figure 6 Performance of next-generation electric compressor

3.2 Water-cooling condenser

The water-cooling condenser is expected to satisfy all the requirements of the space the unit is installed in while providing the necessary functions. Therefore, increased efficiency and downsizing of the unit are achieved by utilizing a plate heat exchanger with a laminated structure of the plates, which forms a flow channel for the bed materials (refrigerants and coolants). (**Figure 7**)

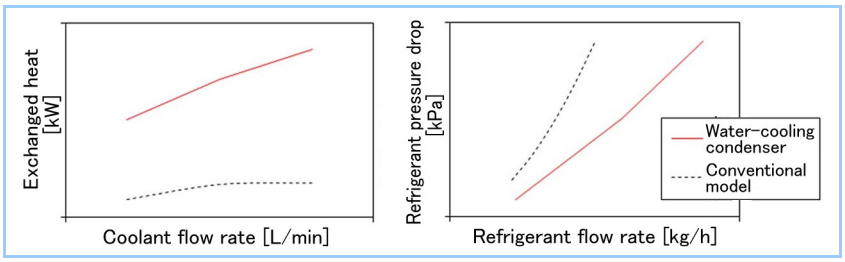

Figure 7 Performance of next-generation water-cooling condenser

3.3 Performance evaluation

Figure 8 shows the results of a heating performance evaluation test on an actual vehicle equipped with the system consisting of the above components to boost the capacity when the outside air temperature is 0°C. It was confirmed that the temperature of the air outlet and the cabin temperature were both significantly increased.

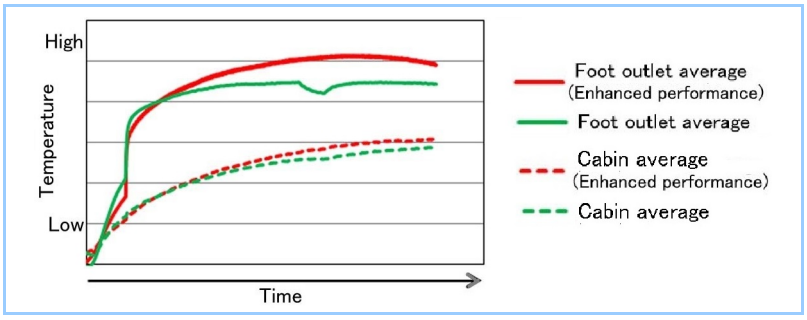

Figure 8 Vehicle heating performance

4. Conclusion

The utilization of the heat pump water heating system enabled the development of the system which achieved some reduction of the power consumption compared with the existing electric water heating system while maintaining the same level of comfort. Accordingly, the EV driving mileage, which is the most important factor in terms of the product value of plug-in hybrid vehicles, is expected to increase dramatically. In this regard, MHI has been working on the improvement and development of the conventional electric water heating system as well, which we hope to be able to combine with the heat pump water heating system as an auxiliary heating system for extremely cold climates. We are determined to strive for the further development of air-conditioning systems for next-generation vehicles, utilizing the benefits from both existing and new models.