

# Practical Approach to Develop Low Cost, Energy Efficient Cabin Heating for Extreme Cold Operating Environment

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## ABSTRACT

In cold climatic regions (25°C below zero) thermal comfort inside vehicle cabin plays a vital role for safety of driver and crew members. This comfortable and safe environment can be achieved either by utilizing available heat of engine coolant in conjunction with optimized in cab air circulation or by deploying more costly options such as auxiliary heaters e.g. Fuel Fired, Positive Temperature Coefficient heaters.

The typical vehicle cabin heating system effectiveness depends on optimized warm/hot air discharge through instrument panel and foot vents, air directivity to occupant's chest and foot zones and overall air flow distribution inside the vehicle cabin. On engine side it depends on engine coolant warm up and flow rate, coolant pipe routing, coolant leakage through engine thermostat and heater core construction and capacity.

The purpose of this study is to evaluate a conventional coolant type heating system and enhance its capacity to warm the vehicle cabin up to comfortable temperatures of +10°C to +15°C in head zone and +15°C to +20°C in foot zones of occupants. These temperatures are to be achieved in 15 minutes after vehicle start, prior to which vehicle has been cold soaked for 10 hours at ambient temperature of 25°C below zero.

A series of experiments have been carried out on a conventional coolant type automotive cabin heating system on a test bench to optimize the split of warm air hitting driver and occupant's chest and leg zone. Further optimization is carried out on directivity and velocities of warm air

impinging on target zones such as upper and lower body of occupants.

Once parameters critical to performance as mentioned above are optimized on a bench, the heating system is mounted inside a vehicle cabin. To improve overall heating effectiveness hot air leakage paths from the vehicle cabin have been identified by using a simple test rig and these paths were closed using grommets and sealant. The vehicle is tested in a cold climatic chamber at 25°C below zero. This trial is conducted on a chassis dynamometer to simulate actual road load conditions. In this phase it is observed that the criteria for thermal comfort are met with the conventional coolant type heating system.

This practical approach to meet thermal comfort requirements at extreme cold conditions, avoids the use of costly and complex auxiliary cabin heaters, which would have led to increase in energy consumption and environment pollution.

## INTRODUCTION

Most practical and economical energy source for automobile is its internal combustion (IC) engine. The actual internal combustion engines are always outcome of complex trade-offs between different parameters such as efficiency, weight, power, heat, response, exhaust emissions or noise. In today's scenario the major driving factors for futuristic IC engine are its high thermal efficiency which is a customer demand and the exhaust emission which is a regulatory requirement. High thermal efficient IC engines allow less waste heat, ultimately poor heat transfer to the engine components and especially to the oil and the coolant. Hot coolant from IC engine is supplied to conventional cabin heating system. At low ambient temperatures a fast warm-up of occupant's

compartment and to meet the requirements of a comfortable cabin heating becomes challenging due to limited heat rejection capacity of efficient IC engines.

Human being is an endotherm and its normal physiological life is possible because of a nearly constant internal body temperature, which fluctuates very little in spite of large changes in the environmental conditions and/or in spite of high amount of internal heat production. In cold climatic conditions; when heat losses are larger than heat production, it is necessary to struggle against drops in body temperatures.

In extreme cold climatic conditions, driver, co driver and crew inside the cabin experiences discomfort due to low ambient temperature. Cabin warm up rate and local temperature at head, waist and foot zone needs to be maintained at different level to provide thermal comfort and operational safety.

The details about conventional cabin heating system (CHS) under consideration are given in [Figure 01](#). CHS is under dash mounted and fitted on cabin floor. CHS mounting on vehicle under test (VUT) is shown in [Figure 02](#). Blower unit has to supply fresh cold air over heating coil, which is distributed through plenum to four vents on IP and two diffusers at foot. [Figure 03](#) shows the heater coil placed in IC engine coolant circuit. Water valve regulates the coolant flow supplied to CHS.

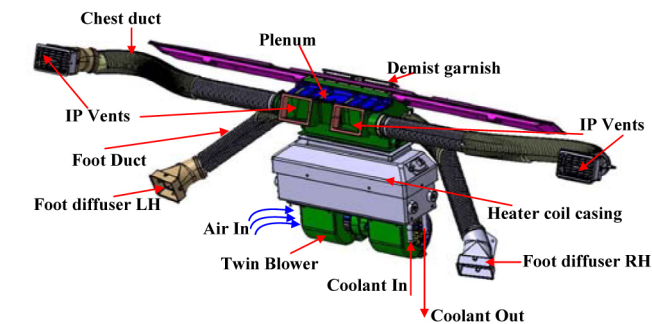


**Figure 01. Cabin heating system (CHS)**

In order to evaluate the cabin heating performance the cabin heating tests were conducted inside the cold climatic chamber on a VUT. The VUT shown in [Figure 04](#) was equipped with the CHS under consideration. The results from tests were contrary to requirement, the head zone temperatures were higher than foot zone resulting in large difference in head and foot temperature.

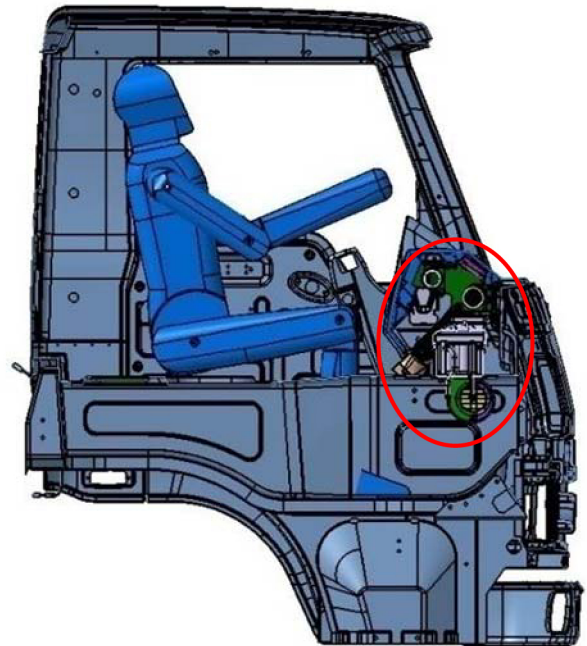


**Figure 02. CHS mounting inside cabin**

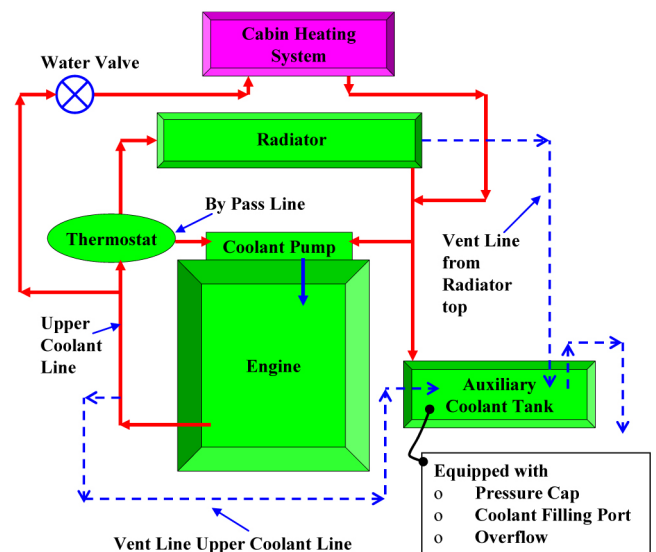


**Figure 03. IC engine coolant circuit**

In this project, CFD simulation is used to improve air flow directivity in leg zone. The total air flow rate, the distribution through IP vents and leg diffusers was measured on a bench. The internal leakages in CHS were identified and sealing was improved. The heating capacity of CHS was verified using a bench test facility.

In order to achieve target temperatures [5] at occupant's head, waist and foot zone; cabin heating tests were conducted with different bi-level mode (chest and leg) air flow distribution

configuration, with and without radiator curtain, with laden and unladen road load application.

CHS effectiveness or cabin heat up rate also depends upon parameters like cab sealing or pressurized cab. The VUT cabin has been tested for cabin sealing and later with improved cabin sealing the VUT has been tested for cabin heating performance. Frank D Eischen [1] conducted lot of experiments to produce comfortable cabin.

Cabin insulations contribute to reduce total heating load on cabin heating system. Thermal insulations were re-examined to confirm feasibility for application on VUT. You Ding and Robert Zito [2] discussed in detail about correlation between the overall heat transfer coefficients of any vehicle body style with different type of insulation materials.

This paper discusses a four way practical approach to achieve the thermal comfort inside occupant's compartment without using any auxiliary devices.

## REFERENCE VEHICLE AND VUT STUDY

Figure 05 and Table 01 shows the results from the baseline test conducted on VUT, to evaluate the cabin heating performance at 25°C below zero. Before starting the test, the VUT was soaked for 10 hours at 25°C below zero in cold climatic chamber. Figure 04 shows VUT in cold climatic chamber. The temperature at occupants head zone reached 19°C against target of 10°C, waist zone 8°C against target of 15°C and foot zone 3°C against target of 16°C at 15th minute after starting vehicle.



**Figure 04. VUT in cold climatic chamber**

Similar test as mentioned above was conducted on a reference vehicle. Figure 06 and Table 01 shows test results of the reference vehicle. The temperature at occupants head zone reached 19°C against target of 10°C, waist zone 21°C against target of 15°C and foot zone 16°C against target of 16°C at 15th minute after starting vehicle. The reference vehicle test results when compared to VUT were better and it meets the cabin heating performance targets. VUT needed improvement at foot zone and waist zone to meet cabin heating performance targets.

**Table 01. Reference vehicle and VUT (Baseline) test results**

| Test Condition:<br>Ambient temperature maintained at 25°C below zero.   | Description                   | Average head | Average Foot | Difference between head & Foot | Average waist |
|-------------------------------------------------------------------------|-------------------------------|--------------|--------------|--------------------------------|---------------|
| Temperature (°C) at 15 <sup>th</sup> minute after starting cabin heater | Target                        | >10          | >16          | < (3 to 10)                    | >15           |
|                                                                         | Actual                        |              |              |                                |               |
|                                                                         | Vehicle Under Test (Baseline) | 19           | 3            | 16                             | 8             |
|                                                                         | Reference Vehicle             | 19           | 16           | 3                              | 21            |

## FOUR WAY APPROACH TO ENHANCE CONVENTIONAL CABIN HEATING PERFORMANCE

The main factors governing cabin heating system effectiveness in extreme cold climates are handling of warm air, heating capacity, IC engine coolant heat up rate, vehicle cabin sealing, quality and type of cabin insulations used.

### 1. Air Handling Parameters critical to handling of warm air

- 1.1. Air velocity at head, waist and foot of occupant
- 1.2. Air flow rate (m<sup>3</sup>/hr or liters/second) from blower to occupant's space
- 1.3. Air flow distribution in head and foot area inside cabin

### 2. Heating capacity

### 3. IC engine coolant heat up rate

- 3.1. Masking of the radiator and intercooler
- 3.2. Laden and unladen road load condition

### 4. Vehicle cabin parameters

- 4.1. Cabin sealing
- 4.2. Insulations used at cabin floor, firewall and sidewall

All above mentioned parameters were studied on VUT. The approach followed to improve and meet the performance target is discussed below in detail.

## 1. AIR HANDLING

### 1.1. CFD simulation for improving air directivity in leg zone inside cabin

Simulation plays an important role in predicting the component performance and its behavior at different operating conditions. 3D CFD simulation was used to predict airflow directivity at driver leg area. Figure 07 and Figure 08 are showing the baseline and improved results. Figure 09 is showing velocity contour in driver's leg zone baseline and

improved. The airflow was directed at driver's right leg. The foot ducts design was modified. CFD simulation was again carried out.

With this modified design air directivity on driver's right and left leg was improved. Similar activity was carried out for co driver leg zone also.

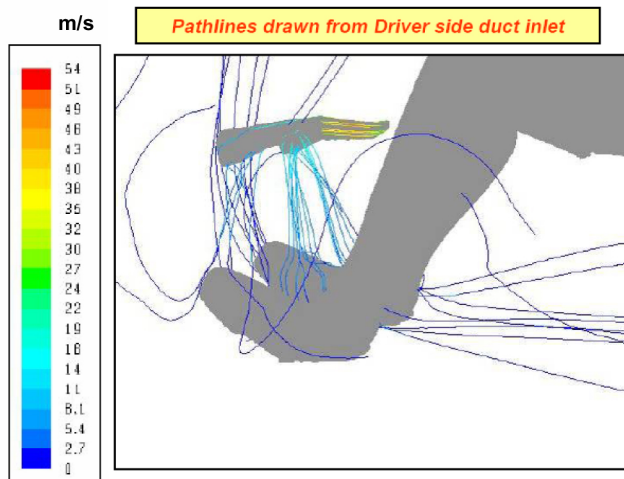


**Figure 07. driver- Foot Duct directivity analysis (Baseline)**

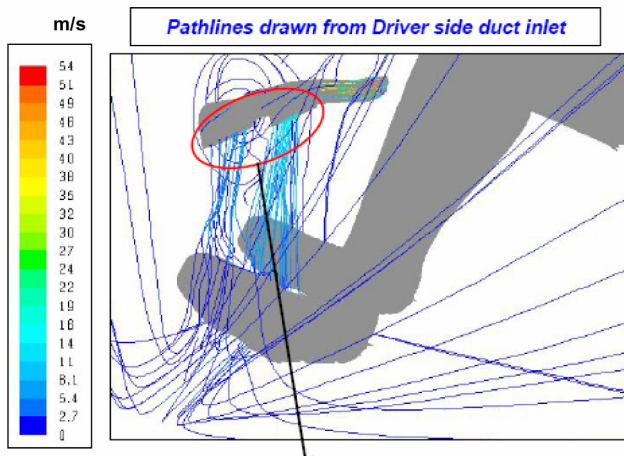


**Figure 08. Driver- Foot Duct directivity analysis (improved)**

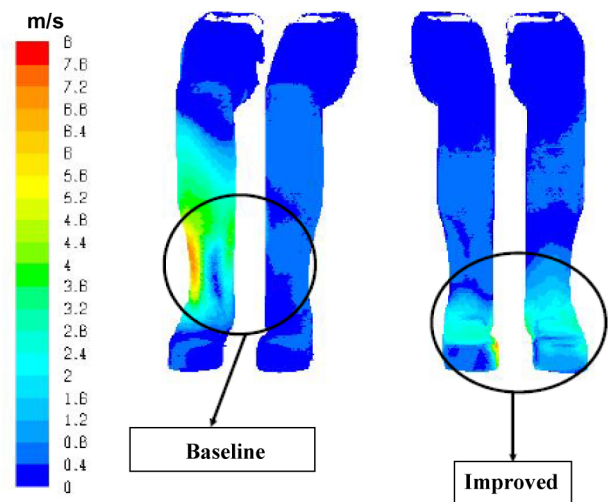


**Figure 09. Velocity contours on driver foot area**

## 1.2. Identification of leakages and improving bi-level (chest and leg) air flow distribution

Hot air leakage through CHS is detrimental. Air flow through cabin heating system was improved by closing leakages through joints and by using good quality foam sealing. The sealing of heater coil in CHS was improved to avoid cold air by-passing from sides, top and bottom of coil.

Figure 10 shows the test bench prepared to study changes in plenum at different bi level air flow distribution levels. Airflow measurements were carried out to check total air discharge from the plenum, Refer Figure 11.

Distribution of airflow was achieved by several iterations and with specific changes in plenum. Different cabin heating systems were prepared to give air flow distribution of 70%-30%, 30%-70%, 50%-50% at chest and leg level respectively. Table 02 is showing summary of different configuration and bi-level (chest and leg) percentage air flow distribution. These configurations were updated on VUT and tested for cabin heating performance.

The 4<sup>th</sup> configuration 50%-50% at chest and leg level gave uniform air flow distribution and air velocities at occupants (driver and co driver) head, waist and foot area.

**Table 02. Plenum configuration for different air flow distribution inside cabin**

| Plenum Configuration                                                              | Bi level mode (Chest and Leg) (air flow distribution) |                      |
|-----------------------------------------------------------------------------------|-------------------------------------------------------|----------------------|
|                                                                                   | Airflow at Chest level                                | Airflow at Leg Level |
|  |                                                       |                      |
| 1                                                                                 | 0%                                                    | 100%                 |
| 2                                                                                 | 30%                                                   | 70%                  |
| 3                                                                                 | 70%                                                   | 30%                  |
| 4**                                                                               | 50%                                                   | 50%                  |

Changes incorporated in air handling system are shown in [Figure 12](#) (configuration 3 which gives 70%-30% air flow distribution) and in [Figure 13](#) (configuration 4 which gives 50%-50% air flow distribution).

**Air distribution System Configuration**

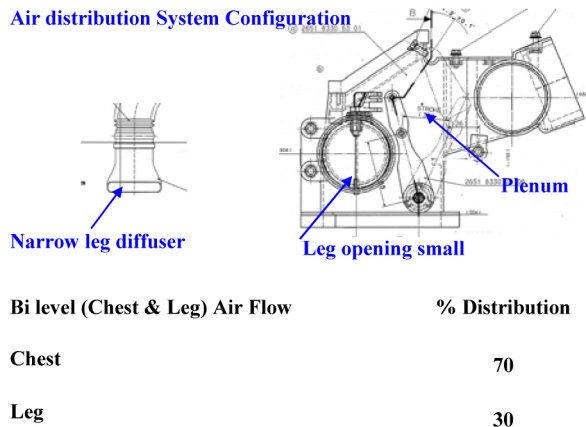


**Figure 12. Airflow distribution configuration 3**

**Air distribution System Configuration**

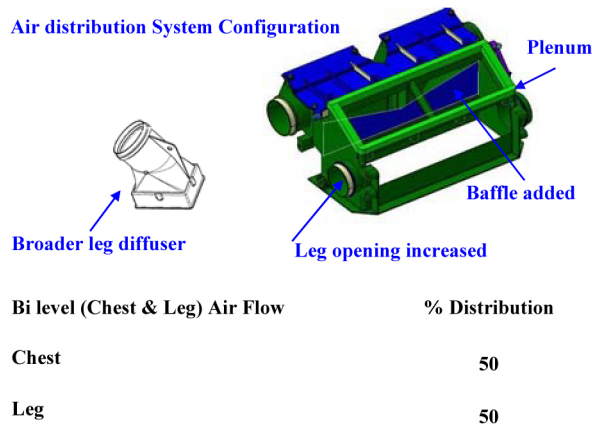


**Figure 13. Airflow distribution configuration 4**

## 2. VERIFICATION OF HEATING CAPACITY

A heating capacity of at least 7.5 KW is required for raising the temperature inside a cabin with volume 3 m<sup>3</sup> to 4.5 m<sup>3</sup> from 25°C below zero up to +15°C. System bench was deployed to measure the heating capacity of the heating unit assembly. The air and coolant (hot fluid) temperatures and flow rates were measured at each appropriate location. [Figure 14](#) shows the schematic layout of the bench test arrangement. Results of system bench test are graphically mapped to capture heater capacity at different coolant flow rates (LPM) and different air flow rates (m<sup>3</sup>/hr). Refer [figure 15](#) for test results.

It is observed that the cabin heating system was able to deliver required heating capacity of 7.5 KW (25614 BTU/hr) at an air flow rate of 400 m<sup>3</sup>/hr and coolant flow rate of 16 LPM.

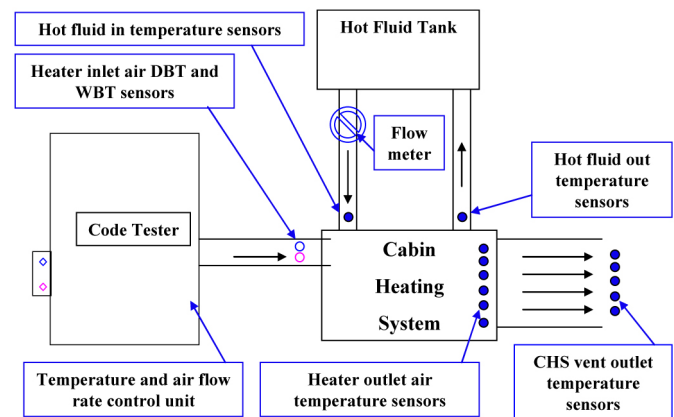


**Figure 14. Bench test setup for evaluating heating capacity**

## 3. IC ENGINE COOLANT HEAT UP RATE

### 3.1. Impact of masking radiator and intercooler

This study was conducted to see the effect of ram air at extreme cold climate. A curtain was provided in front of engine radiator and intercooler. [Figure 16](#) and [Table 03](#) shows the test result of VUT with and without curtain.

Masking the radiator and intercooler gives engine coolant temperature rise 11°C and resulting into average cabin temperature rise of 8°C at 15<sup>th</sup> minute after starting vehicle. Masking the radiator and intercooler reduces ram air quantity; it helps to improve engine heat up rate.