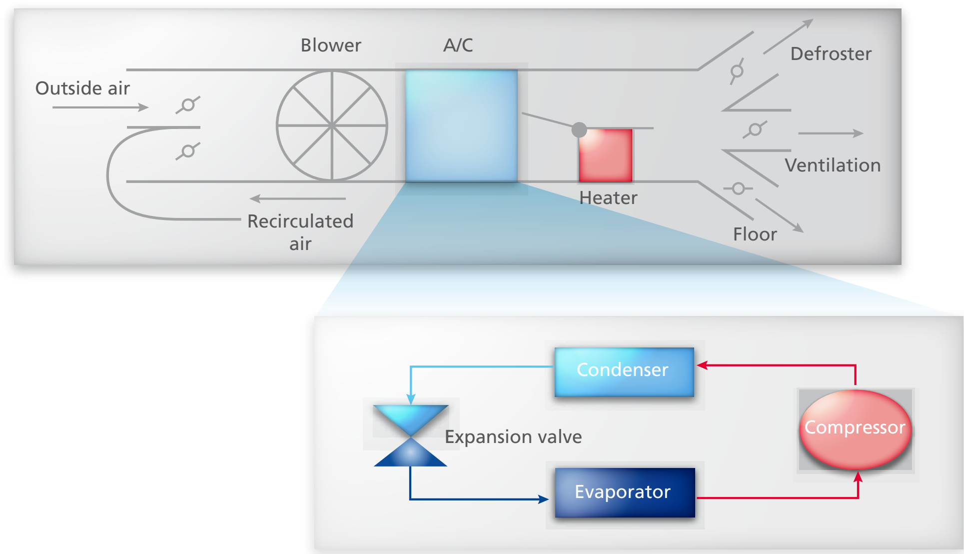
Climate Under Control

Volvo Technology develops climate control software with TargetLink

Volvo Technology, the center for innovation, research and development in the Volvo Group, has been continuously refining and extending its established Climate Control Module (CCM) over the years. The software is used by several international car, truck and construction equipment brands. Volvo Technology makes intense use of TargetLink during the controller development, autocoding and tuning phases.



Simplified view of the climate unit (HVAC: heat, ventilation and air condition).

Better Climate with CCM

Volvo Technology's main role for climate control developments is to deliver software which fulfils modern climate comfort requirements and addresses issues such as air demisting, odor and noise control, and energy efficiency. Current development is focused on improved efficiency in calibration for new vehicles and incorporation of new features and requirements. The development cycles are highly test-driven, and testing and tuning using prototypes and pre-series vehicles are common. dSPACE's production code generator TargetLink plays a major role in Volvo Technology's development process for function design, autocoding, tuning and testing.

What Makes a Good Climate Control?

Good climate control lets drivers select their preferred setting and then get exactly the comfort they expect. This means that the temperature in the passenger compartment is kept within a predefined range, there is no draught, the fan is not too noisy, it does not get cold when the sun goes in, the windscreen does not mist up, and so on. To achieve all this, a climate controller has several control objectives:

- **Temperature Control**
This controls the heating, cooling, blower and air distribution to achieve fast heat-up/cool-down and a stable interior temperature in the passenger compartment during different driving conditions. It also compensates for disturbances such as high/low ambient temperature, sun load and vehicle speed.

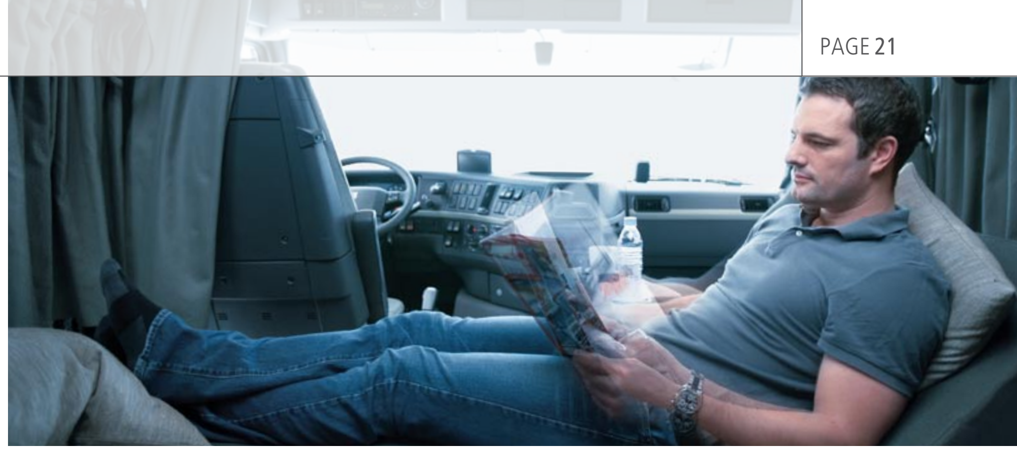
- **Demisting Control**
The purpose is to keep the windscreen free from ice and mist. The control mainly uses the blower, defroster and cool/reheat with air conditioner (A/C) and heating system.

- **Odor Control**
The odor control, commonly known as AQS (Air Quality System), prevents unpleasant odors from entering the compartment via the outside/recirculated air flaps.

- **Parking Climate**
Passenger cars and commercial vehicles both have functions for controlling the interior climate while parked. In trucks, where the driver often stays in the cab overnight, this is particularly important and sets strict requirements on temperature comfort and noise.

Typical Hardware for Climate Control

Climate control requires a number of hardware items to make the control software work the way intended. One of them is the climate unit, often referred to as HVAC (heat, ventilation and air Condition). The recirculation enabled by the climate unit is primarily used for improving the cooling performance in a hot climate by recycling the air already cooled and dried. Another use of recirculation is for preventing odors and pollution from entering the compartment. The part of the HVAC that cools the air is the air conditioner (A/C), consisting of compressor, condenser, expansion valve and evaporator. A number of sensors are also important for climate control. Some of them, such as the passenger compartment temperature sensor and the evaporator temperature sensor, are typical of an Electronic Climate Controller (ECC). Other sensors such as the vehicle speed sensor or the ambient temperature sensor primarily exist



for other systems in the vehicle, but are also important to the ECC.

Inside the CCM

The CCM is part of the electronic system in the vehicle and is connected to other subsystems on the networks via CAN and LIN. Some sensors and actuators are also hardwired to the CCM. The Climate Control itself provides all the functions described above, i.e., temperature control, demisting control, odor control, and parking climate. The CCM has been modularized into several functions. The controller input signals are processed first. This includes basic filtering and error handling as well as some sensor fusion and modeling to the data needed for the control algorithms. The controller structure is then function-oriented rather than actuator-oriented. This means that the modules for temperature, demisting and odor control all request actuator actions. After controller actions are prioritized, manual overrides from the driver are taken care of, and finally actuator actions are sent.

Overview of the Development Process

The CCM is an established product and so is the development process for it with TargetLink. Typically, new developments require the fine-tuning or extension of functionalities already present in the CCM, so that existing resources like software requirements, TargetLink models and test cases from previous projects are reused and adapted to meet the new requirements.
In a simplified view, four different types of activities can be identified in the process:

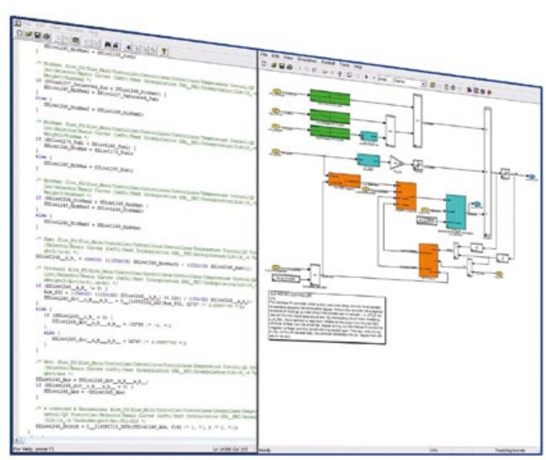
- Software requirement specification
- Control design and implementation
- Controller tuning
- Test & validation.

The development process is highly test- and experiment-driven and iterative. This is because a lot of the testing and fine-tuning for the CCM can only be done in-vehicle due to the difficulty in modelling the subjective perception of occupant comfort. This means that changes and updates to the control design need to be made iteratively to compensate for behavior overlooked in the initial stages of software requirement specifications and control design.

Software Requirement Specification

Requirements are supplied by the customer on a system level. These are often end customer use cases in the form of "Head level temperature must be between X and Y °C". During the first iteration of the requirement specification phase, the system requirements are decomposed into meaningful software requirements. Some software requirements are also reused from previous projects. In subsequent iterations, some software require-

> "We autocode almost 100% of the application layer of our Climate Control Module with TargetLink."
>
> *Dr. Mats Andersson, Volvo Technology*



Controller model and code: TargetLink was used to autocode almost the entire application layer of the CCM.

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ments need to be adapted as a result of in-vehicle tests and tuning.

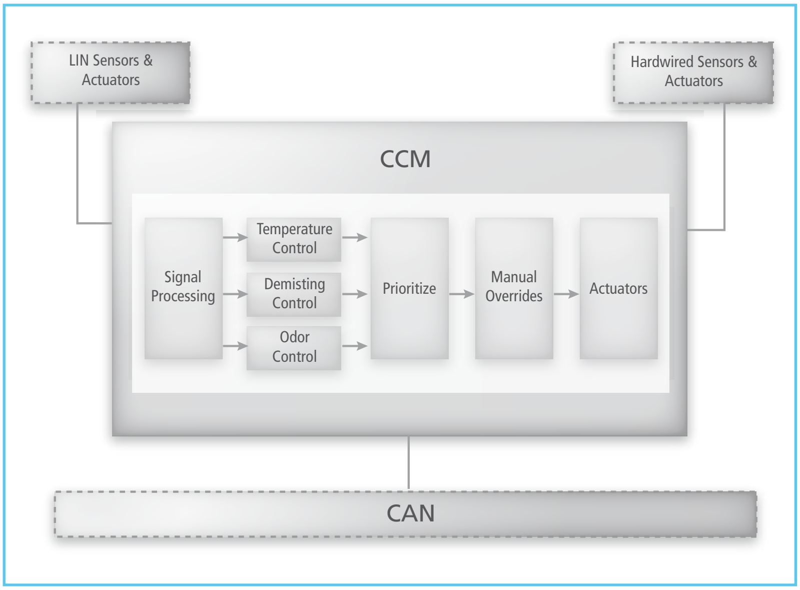
Controller Implementation

The core functionality of the CCM exists in the form of a TargetLink model from which code has been deployed for various production projects. The actual control design is carried out entirely by Volvo Technology using the TargetLink Stand-Alone Blockset. The largest part of the control design work is done in the first iteration of the development process, where the existing TargetLink model is adapted to meet the new software requirements. In subsequent iterations, the control design is modified to reflect necessary changes in software requirements during the course of the project.

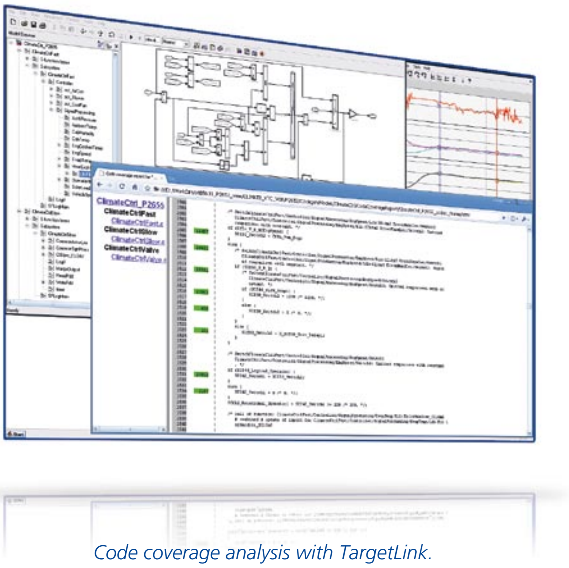
Control design and implementation with TargetLink almost go hand in hand. Close to 100% of the application layer of the CCM is autocoded by TargetLink in the form of efficient fixed-point code. Moreover, TargetLink's flexibility enables the generation of interfaces that are very well suited to a later integration into the software architecture of the CCM.
Open loop and closed loop simulations are used to inspect the basic behavior of the controller as well as the generated code. Actual stimuli which were captured in vehicles and some simplified plant models are used for the simulations.,The overall system behavior of the controller is examined in floating-point arithmetic with Model-in-the-Loop (MIL) simulations. Software-in-the-loop (SIL) simulations are used to verify the behavior of the generated code for the controller. TargetLink's integrated simulation concept is used to compare MIL with SIL simulations to detect improper scalings in the implementation model. The result of the Control Design and Implementation phase is a properly scaled TargetLink model and code generated from it.

Controller Tuning

Climate control essentially means controlling the air into the passenger compartment. The plant models used during the control design and implementation phase do not capture all of the subjective aspects of comfort and noise. Consequently the final tuning of the controller is performed in-vehicle, often starting in a prototype vehicle where some of the hardware is changed from an existing vehicle. In order to carry out the tuning, the TargetLink code generated for the implementation model is integrated into the real-time frame of the application, compiled, and flashed to the climate ECU of the vehicle. Moreover, a TargetLink-generated ASAP2 file is used to adapt the calibration parameters, so that the CCM can be tuned efficiently and its functionality verified. Initial tuning experiments and tests are performed in a controlled environment such as a climatic wind tunnel. Later in the project, road tests are most common. The refined controller tuning is gradually refined as the overall project evolves.



Physical interfaces to the Climate Control Module (CCM) and CCM controller modularization.



Code coverage analysis with TargetLink.

Test and Validation

Extensive testing is done before the software is delivered for vehicle production. Typically, model-in-the-loop and software-in-the-loop tests in TargetLink are executed for module testing. This involves functional as well as structural tests. TargetLink's code coverage feature is used extensively to ensure sufficient coverage of the generated code. There are also general tests, and the results of those are compared to previous simulations and evaluated together with tuning. This is often done manually, since the tests are general and need to be evaluated by a highly skilled climate control engineer. System and software integration testing is carried out on the actual ECU using a dSPACE hardware-in-the-loop simulator. Generally, many test cases are reused throughout the different development phases in model-in-the-loop, software-in-the-loop and hardware-in-the-loop mode which makes the testing process efficient. ■

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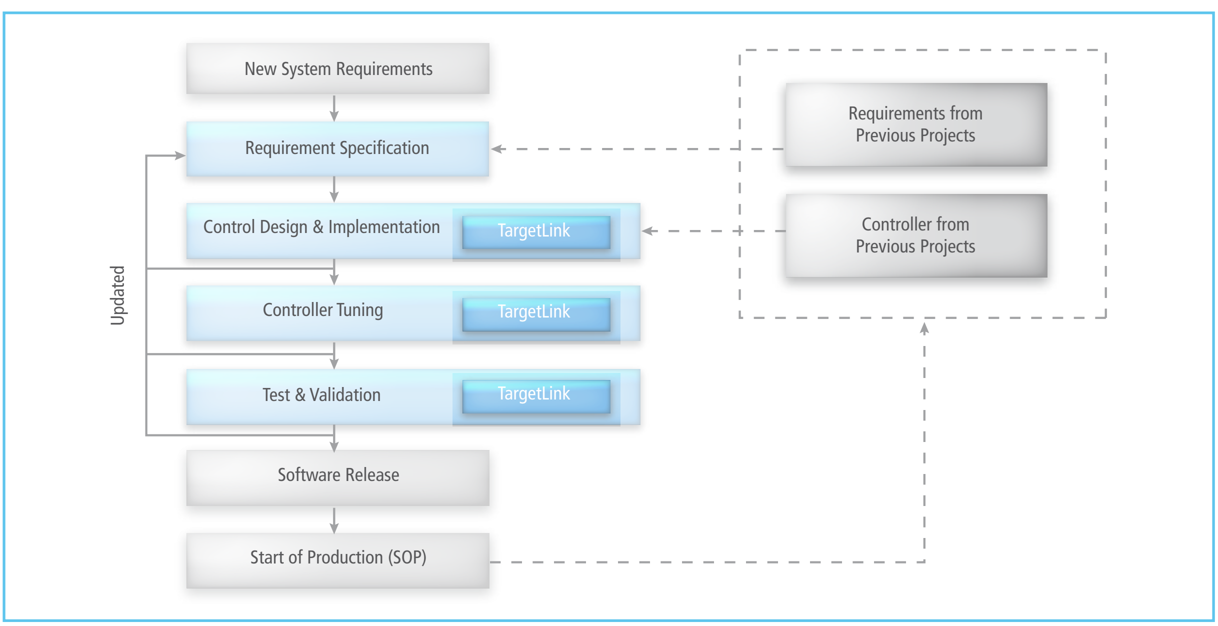
Conclusion

- Volvo Technology's Climate Control Module (CCM) has been refined and extended over the years
- Successful use of TargetLink for controller development, autocoding and tuning
- Almost the entire application layer of the CCM was autocoded with TargetLink
- CCM is used by several international car, truck and construction equipment brands



Iterative development process for the Climate Control Module (CCM).