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Nicholas Carsten Lemke
j.lemke@tu-bs.de

Julia Laura Lemke

Juergen Koehler

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Secondary Loop System for Automotive HVAC Units under Different Climatic Conditions

Nicholas Carsten Lemke[1]*, Julia Laura Lemke[1], Juergen Koehler [1]

[1] Technische Universität Braunschweig,
Institut für Thermodynamik, Germany
Contact Information (n.lemke@tu-bs.de)

* Corresponding Author

ABSTRACT

Within the framework of the energy management of passenger cars new driving concepts like those with start-stop-mode require an adaption of the HVAC system. Indirect systems with secondary loops might be a possibility to face these new requirements.

As a part of the European “TIFFE” project (Thermal Systems Integration for Fuel Economy) a secondary loop system for mobile HVAC applications is currently in development. Among other things, the project pursues the realization of a compact and hermetic refrigeration unit called CRU with two secondary loops. Through applying a CRU some relevant advantages like the implementation of flammable or toxic refrigerants, the easy exchangeability of the HVAC system, or lower refrigerant charges might be achieved.

Within this publication the modeling of the whole system as well as a CRU test rig with two secondary loops will be shown. Experimental and simulation results will be presented. For the cycle simulation the advanced Modelica library TIL Suite will be used. By utilization of a virtual test drive the influence of different climatic conditions and operation conditions like start-stop-mode will be shown.

Part of the work at the Technische Universität Braunschweig within the TIFFE project deals with the use of phase change materials (PCM) for heat and cold storage implemented in the secondary loops. Macro-encapsulated paraffin could be one promising type of PCM for mobile applications. Measurement results for this kind of material and the influence of the PCM on the whole system will be presented.

1. INTRODUCTION

In the near future, the vehicle thermal energy management of vehicles will become a relevant issue that will be crucial to achieve the CO_2 emission targets. The conventional approach uses an additional heat exchanger for every extra component to be cooled. This increases costs and might also decrease the efficiency of the system.

An integrated and innovative approach is required to make the vehicle engine and energy systems effective with limited impact on the vehicle architecture and the design of the vehicle front end. Within the presented project “TIFFE”, an appropriate system based on a secondary loop HVAC system is currently in development.

2. SECONDARY LOOP SYSTEM

The TIFFE project focuses on the development of an integrated thermal management system for cars and light commercial vehicles. Its function is to control the temperature of the entire engine and vehicle auxiliaries system and to reject the heat to the ambient. The energy transfer between the heat sources and heat sinks is realized by using secondary fluids like water-glycol-mixtures. The system is based on three loops: Heat of equal temperature levels is rejected through a high and a low temperature loop. Cooling power for compartment or component cooling is distributed via a third loop (see Figure 1). This architecture allows a very large system flexibility, modularity, and controllability.

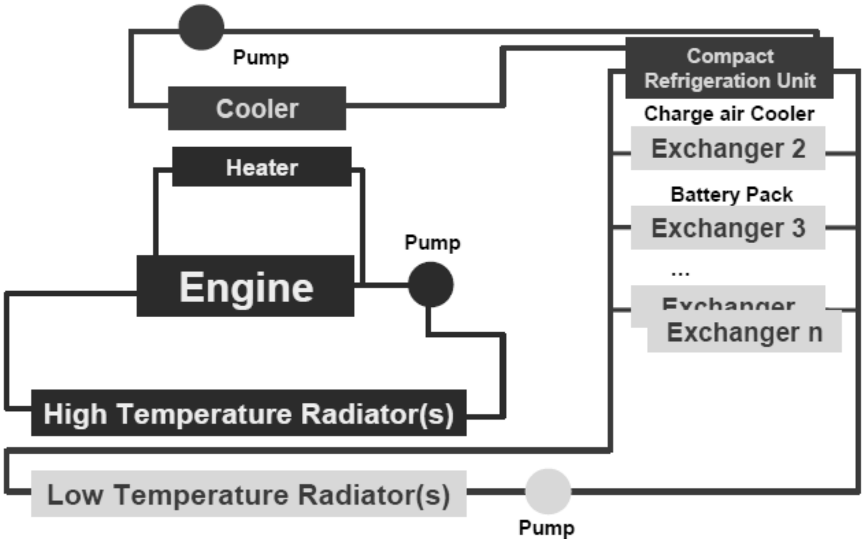

Figure 1: TIFFE basic concept (Seccardini *et al.*, 2011)

2.1 Compact Refrigeration Unit (CRU)

Chilled water for the air conditioning of the passenger compartment is provided by a so called compact refrigeration unit (CRU). Figure 2 shows a scheme of such a system. As a special feature the condenser uses a separated sub-cooling section. In order to ensure a most efficient operation this section uses double cooled heat transfer fluid as a heat sink. The front thermal module has a special sub-cooling area for this purpose (see Figure 3).

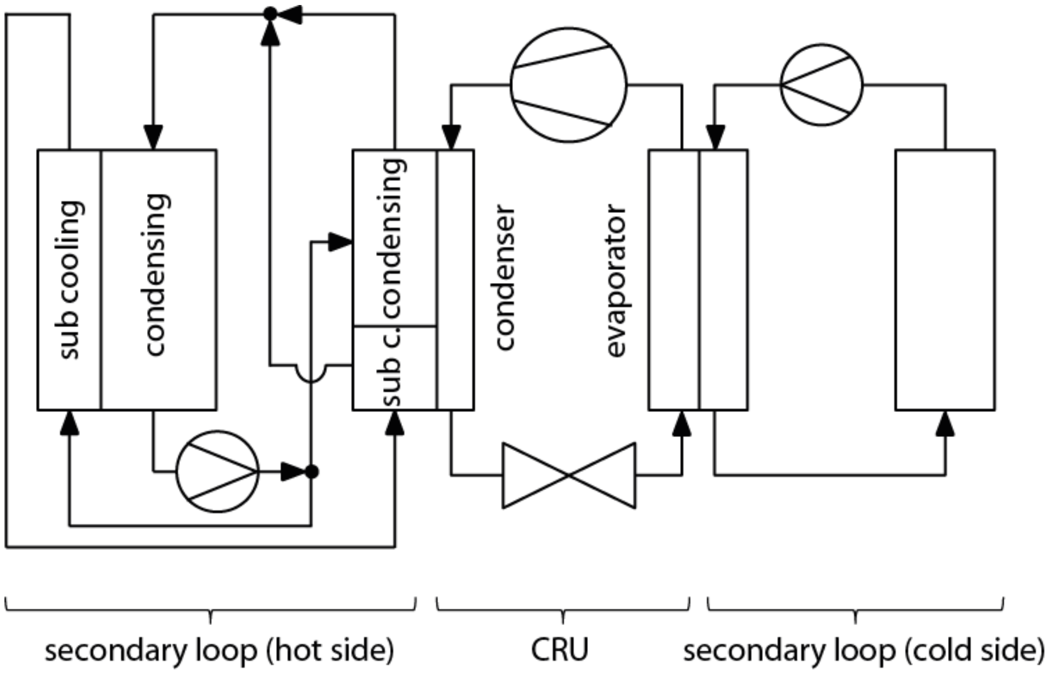

Figure 2: Schematic diagram of a compact refrigeration unit (CRU) with secondary loops

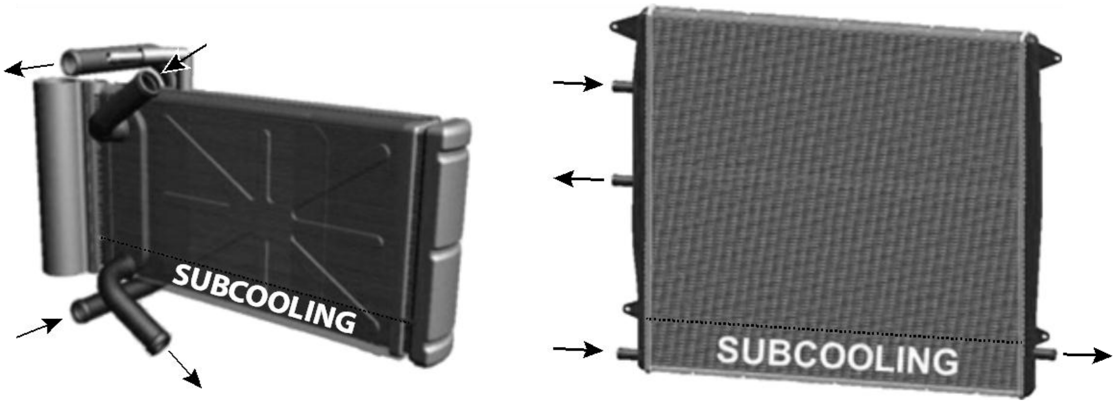

Figure 3: Liquid cooled condenser (left) and front thermal module (right) with sub-cooling sections (Seccardini *et al*., 2011)

Equipped with an electrically driven compressor the CRU can be built hermetically with a very low charge of refrigerant. This might support the use of flammable, high pressure, or expensive refrigerants. Additionally, this unit allows an easy implementation of a heat pump function without any major modifications of the CRU - it only requires a change of the coolant circuit.

2.2 Heat Transfer Fluids and Phase Change Material (PCM)

Using an additional heat transfer fluid on the evaporator side increases the thermal mass of the HVAC system and thereby also decelerates the dynamic of the cooling. This might be a disadvantage during cool down but on the other hand it could help to keep the comfort high during periods of stopped compressor (e.g. start-stop system of the car at a traffic light). Both aspects will be discussed in more detail in chapter 4.2. In the following section, the increase of this effect by using phase change material will be discussed.

Ideal PCM does not increase its temperature while absorbing heat during the phase change (see figure 4). The temperature level of the phase change is given by the material. Suitable material for the evaporator side of an HVAC application should show a phase change somewhere in the temperature range between 0°C and 10°C to prevent icing of the heat exchanger on the one hand and to show a maximum effect on the other. Paraffin-based PCMs meet these requirements.

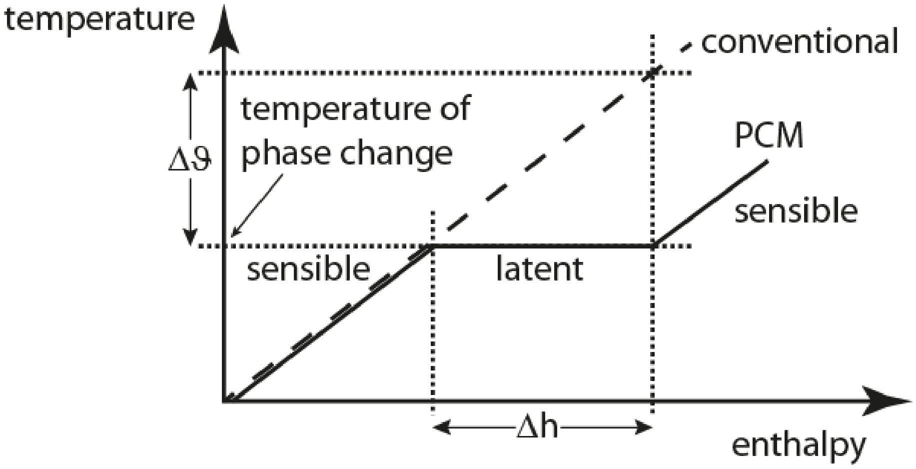

Figure 4: Temperature of PCM during heat absorption

Two different approaches to the integration of PCM have been investigated within the project: Micro-encapsulated polystyrene-coated paraffin that flows as particles inside the heat transfer fluid (phase change slurry) and macro compound paraffin in a bulk package container perfused by the fluid (see Figure 5).

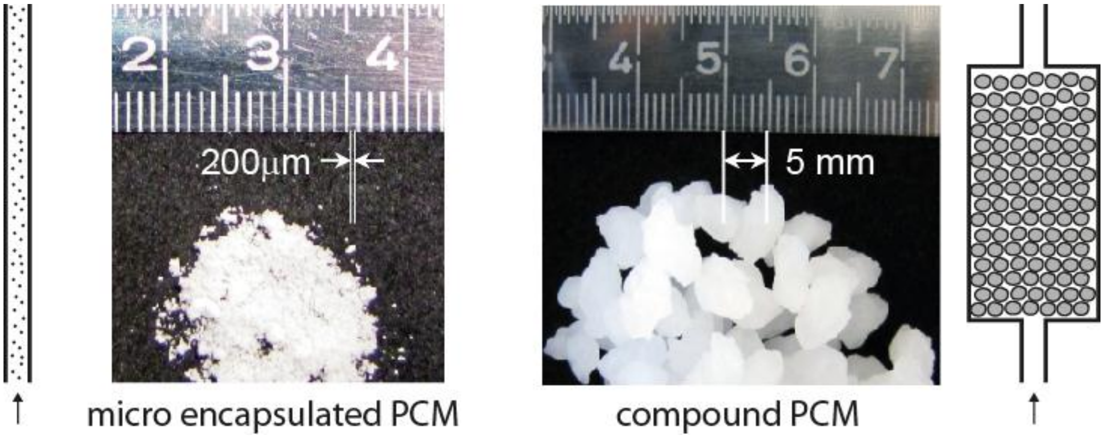

Figure 5: Micro-encapsulated polystyrene-coated paraffin (left) and compound in a container (right)

After some hours of operation the micro-encapsulated polystyrene-coated paraffin showed an abrasive effect on the impeller of the pump. Furthermore, the paraffin capsules tended to agglomerate (see Figure 6). Subsequently, only the compound system was investigated within the project in detail.

Figure 6: Abrasiveness and agglomeration of micro-encapsulated polystyrene-coated paraffin

2.3 Experimental Work

Two different test rigs have been built within the TIFFE project at the Institut für Thermodynamik. A CRU test bench allows the evaluation of the prototype heat exchangers and the analysis of the compact cycle itself. The PCM test rig was specially designed to investigate the performance of different PCM integrated in a secondary fluid flow.

2.3.1 CRU test rig

A CRU test rig was recently completed at the Institut für Thermodynamik (see Figure 7). The main components are: the first generation prototype of the water cooled condenser with sub-cooling, a commercial plate type evaporator, an electrically driven compressor, and an electronic expansion device.

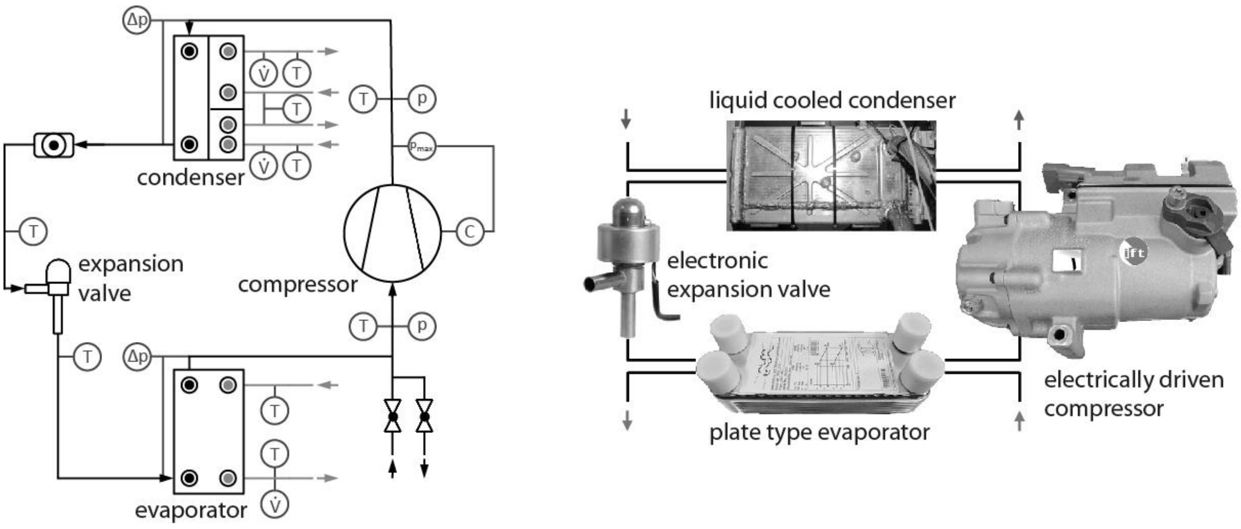

Figure 7: CRU test rig at the Institut für Thermodynamik

First measurements show the principle operation of the test rig and the liquid cooled condenser (see Figure 8). The sub-cooled liquid refrigerant exits the condenser with a temperature of 32°C while the water-glycol-mixture has a temperature of 31°C at the inlet. More comprehensive measurements that will characterize the condenser in detail are currently being prepared using the methods of DoE.

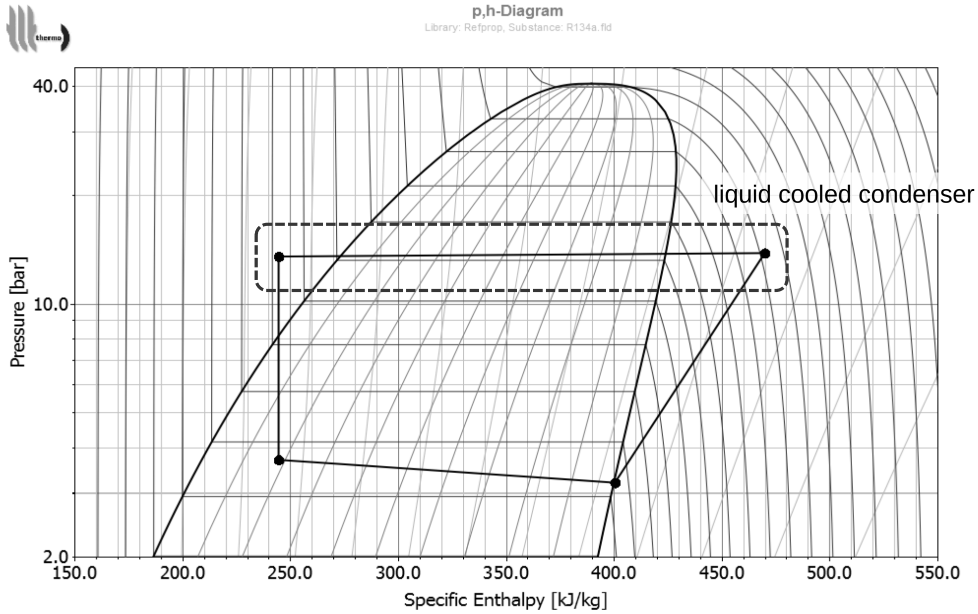

Figure 8: Pressure-enthalpy-diagram of the CRU with the first generation prototype condenser

2.3.2 PCM test rig

In addition to the CRU, a test bench dedicated to the measurement of PCM in the secondary loop was built. A schematic drawing of the test rig can be seen in Figure 9. The heat transfer fluid can perfuse or bypass the PCM container. The fluid may be heated or cooled by an electric heater and a cooled plate HX respectively. All relevant quantities like temperatures or volume flow rates are measured.

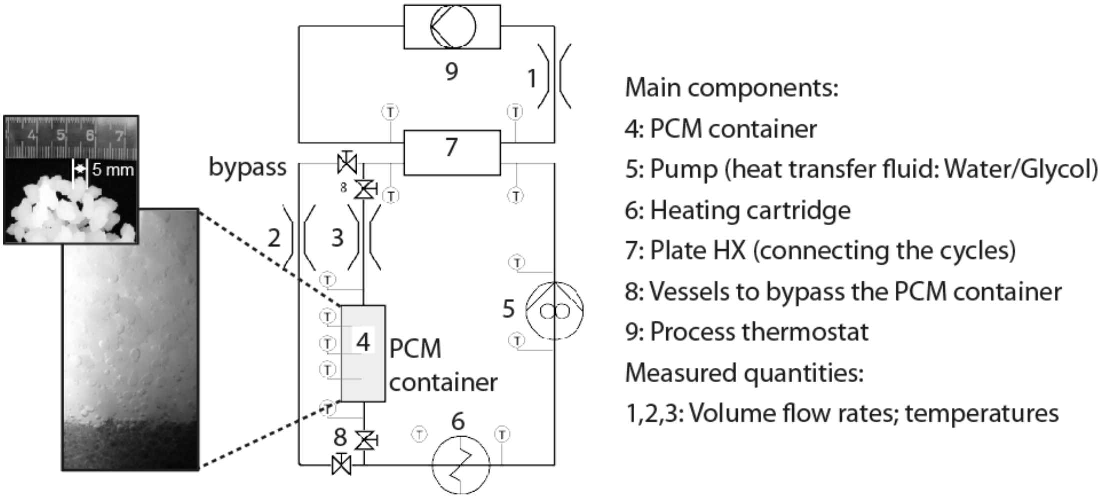

Figure 9: PCM test bench

The results of a typical measurement are shown in Figure 10. The water-glycol-mixture had a temperature of -0.5°C at the start of the experiment. It was heated up with a heating power of 270W. In the first 100 seconds, heat was only stored as sensible heat, resulting in a linear raise of temperature. In the subsequent 150 seconds, the phase change of the PCM delayed the temperature increase. As a result, a threshold value of 6°C was reached 50 seconds later than it would be expected without phase change. This additional gain of time could be used to increase comfort and to safe energy in a car HVAC system. More details will be discussed in chapter 4.

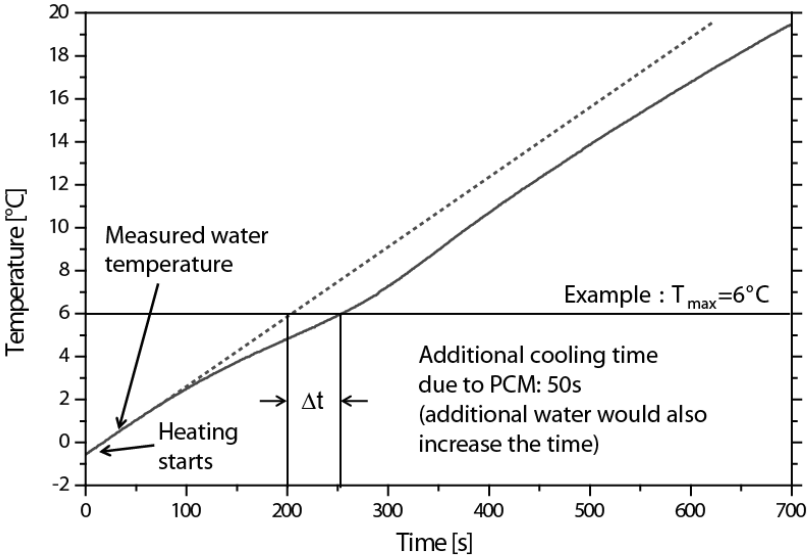

Figure 10: Heating-up test of PCM in a water-glycol-cycle

3. SIMULATION SETUP

Within the project, a simulation of the CRU, the secondary loop (with and without PCM), and the cabin of the Daily IVECO test vehicle were built using Modelica and TIL Suite. Some simulation results will be presented in chapter 4.

3.1 Refrigeraton Cycle and Secondary Loop

Figure 11 shows the graphical representation of the Modelica/TIL Suite (Tegethoff, 2010) model of the A/C cycle, the secondary loop, and the cabin model. For the A/C cycle standard models of the library have been used equivalent to the test vehicles’ components that were built within the TIFFE project. The PCM was modeled to fit the measurement results of the test rig shown in the previous chapter. The cabin model will be discussed in chapter 3.2.

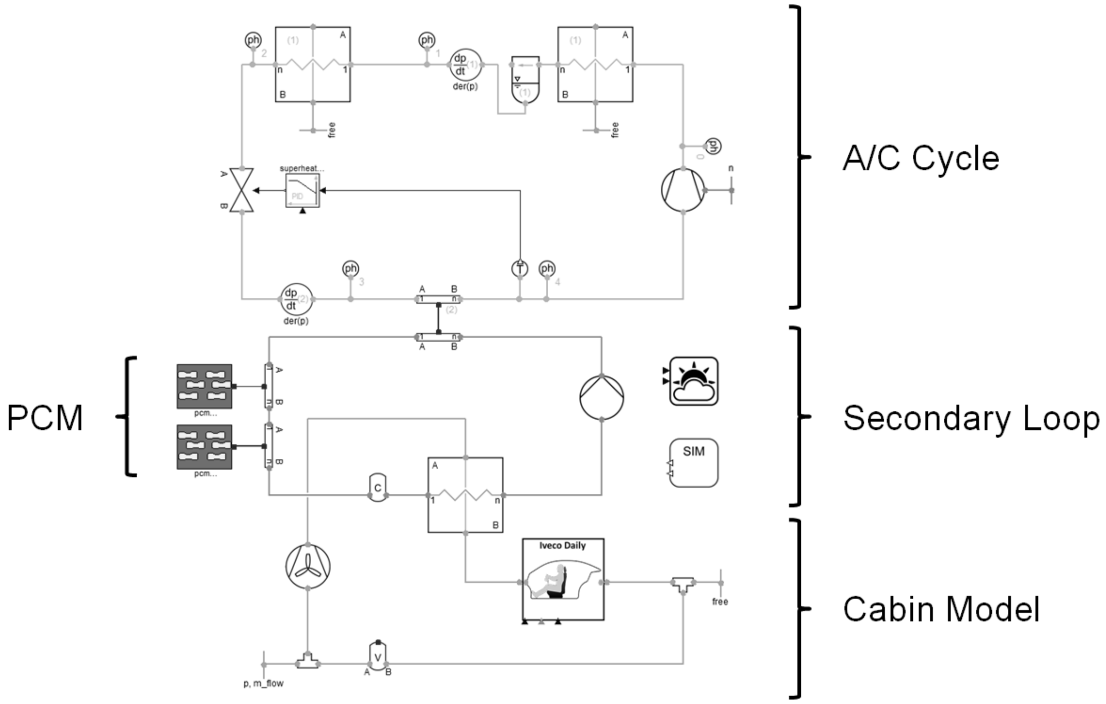

Figure 11: Graphical representation of the Modelica/TIL Suite model

3.2 Cabin Model

A one-dimensional simulation model of the test vehicle cabin was built as shown in Figure 12. The main components were modeled according to the geometry of the IVECO Daily. Radiant and convective heat transfer is included in the model as well as the exchange and moisture handling of the air in the cabin.

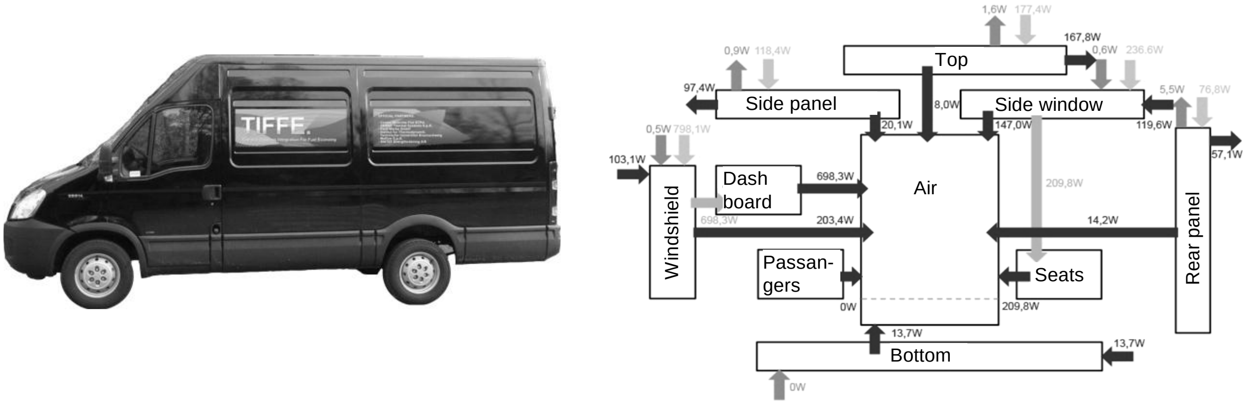

Figure 12: Cabin model of the Daily IVECO test vehicle built with TIL Suite Add-On Cabin

The cabin model was adapted to the geometry of the Daily IVECO test vehicle and fit to cool down measurements of the vehicle. Figure 13 shows a comparison between the simulated cool down of the vehicle and measurements.

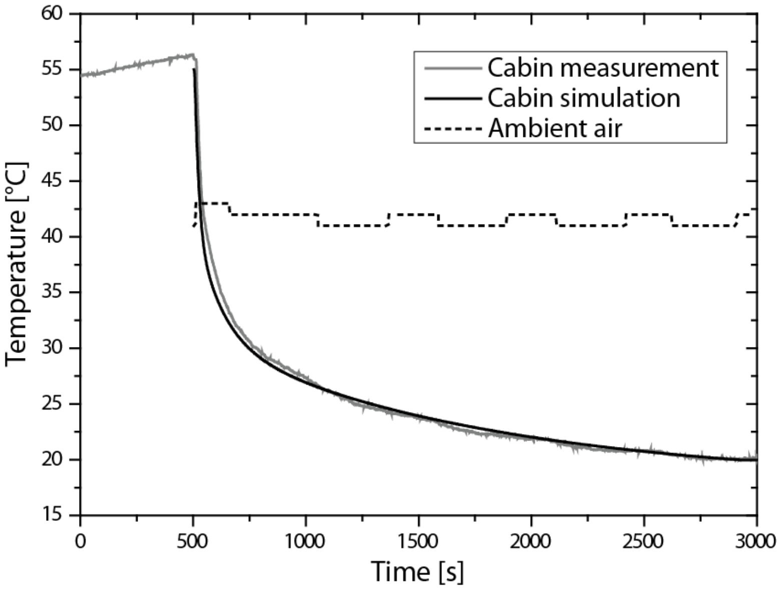

Figure 13: Cool down of the Daily IVECO measurements vs. simulation

4. VIRTUAL TESTDRIVE

In order to analyze the impact of an optional integration of PCM in the secondary fluid cycle, the presented simulation setup was used. A simulated one-hour trip with several stops was used for this purpose.

4.1 Route Example and Ambient Conditions

The exemplary route in this study started on July 21st near Rosenheim (Germany) and ended one hour later in the city center of Munich (see Figure 14). The driving speed was determined using standard route planner software. Using the time of the day and the vehicle orientation along with the solar radiation data, the calculation of the solar insulation was allowed.

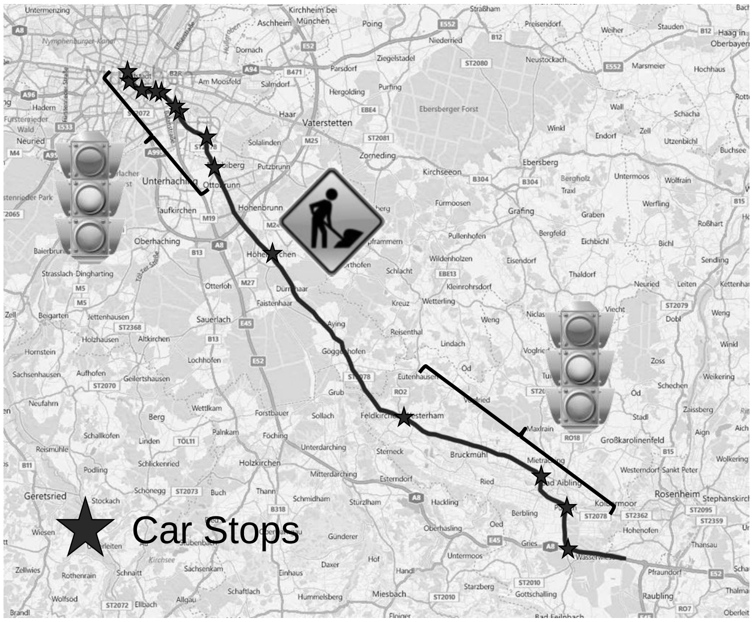

Figure 14: Route of the virtual test drive

The ambient climatic conditions were calculated using the software METEONORM. In Figure 15, the ambient air conditions are shown in a h-x-diagram. Near the end of the trip, higher temperatures were assumed to take into account the so called “urban heat island” near the center of a city (Matzarakis, 2001).

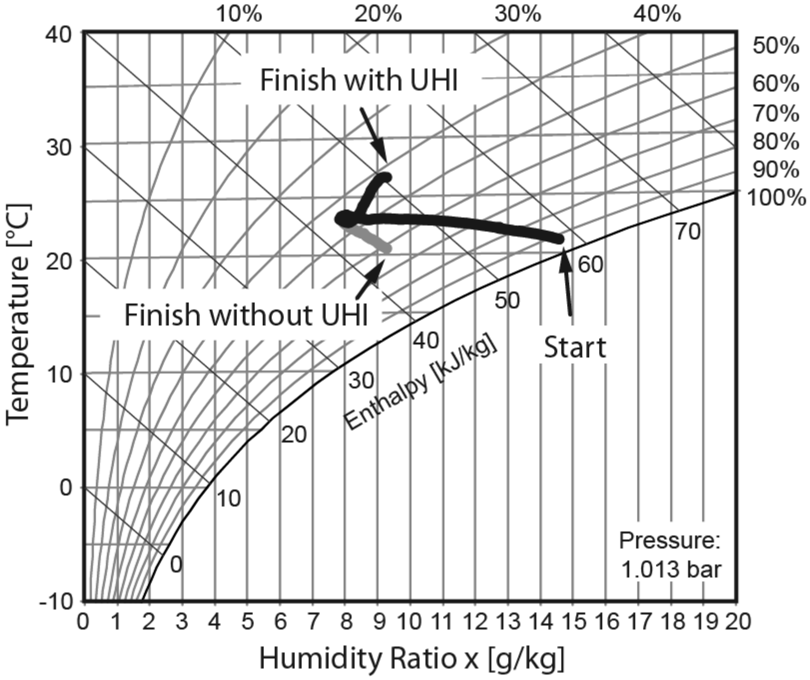

Figure 15: h-x-diagram of ambient conditions during the virtual test drive

4.2 Simulation Results

Figure 16 shows as a result of the simulation the average temperature of the passenger compartment and the temperature at the air inlet into the cabin. Three cases have been simulated: a basic secondary loop system, a system with one liter of additional water-glycol-mixture in the secondary loop, and a system with one liter of PCM instead.

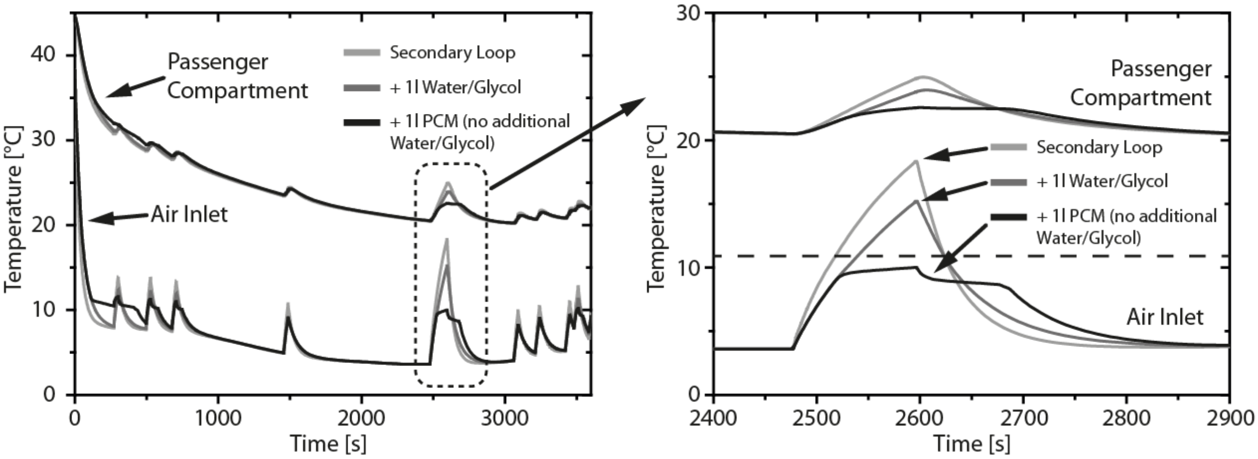

Figure 16: Air temperatures during the virtual test drive

At the beginning of the cool down the basic system shows the most dynamic temperature decrease. The PCM system shows a sharp bend and a slowed temperature decrease as the temperature of the secondary loop fluid falls below the phase change temperature of the PCM. All systems show a distinct temperature increase when the compressor stops due to a motor-off-phase at a traffic light. Later on (t>500s) until the stop at t=2470s all systems show a more or less equivalent performance.

On the right hand side of Figure 16 the longer stop-phase is shown in more detail. All systems show increasing temperatures after the compressor stops at t=2470s. About 50 seconds after the stop, the PCM system can make use of its inherent advantage and keep the air inlet temperature below a level of 10°C for the remaining stop time. The other two systems would have to restart motor and compressor to prevent odor nuisance due to high air temperatures in combination with a wet evaporator.

5. CONCLUSIONS

The TIFFE project focuses on the development of an integrated thermal management system for cars and light commercial vehicles that has the function to control the temperature of all the engine and vehicle auxiliaries systems and to reject the heat to the ambient. Two test rigs for the analysis of a compact refrigeration unit and phase change material within the secondary loop have been presented. A simulation setup using modelica and TIL Suite for the A/C-cycle and the compartment model has been developed.

The simulation of a virtual test drive was presented. The cycle with PCM has shown significant advantages during longer stop phases of the compressor.

REFERENCES

Matzarakis, A., 2001, Die thermische Komponente des Stadtklimas, *Meterologisches Institut der Universität Freiburg*, *Habilitation*, Freiburg

Seccardini, R., Mattiello, F., Malvicino, C., 2011, TIFFE thermal system Light commercial vehicle application, *4th European Workshop on Mobile Air Conditioning and Vehicle Thermal Systems*, Turin

Tegethoff, W., Schulze, C., 2010, Simulation of thermal Systems in SimulationX using TIL and TILMedia, *ITI Symposium 2010*, Dresden

ACKNOWLEDGEMENT

The TIFFE project is supported by the European Community within the 7th Framework Programme.