Chapter 3

Experimental infrastructure

3.1 Introduction

In this chapter description of the developed experimental infrastructure is given. The facilities have been constructed with the objective of experimental validation of numerical models of compact heat exchangers as liquid refrigerant air coolers, liquid overfeed evaporators, and of the overall liquid overfeed refrigeration system with its components.
The experimental facilities are designed in order to study the detailed global performance of the compact heat exchangers and to generate data which can be used to evaluate the numerical model predictions based on the joint simulation of the fluid flow inside the tubes, the air-flow, and the heat conduction in the solids. The liquid overfeed refrigeration system operation can also be studied experimentally in global terms of heat transfer and pressures in the different components.
The infrastructure comprises three instrumented circuits: an air-handling circuit consisting of climatic chamber, compensating chamber and ducts, assuring closed air loop through the tested heat exchanger, a liquid refrigerant circuit, and a phase-changing refrigerant circuit. These three circuits are encharged to provide stable controlled conditions for the tested prototypes and the liquid overfeed system in the desired range of temperatures, fluid flows, and capacities. The design permits the accommodation of heat exchanger prototypes with different geometry and sizes. The measuring instrumentation has been selected to quantify all the physical variables necessary for determining of their heat transfer capacity during the tests independently on the refrigerant- and the air-side, with high accuracy. The measurements in the liquid overfeed refrigeration system permit the determining of the refrigeration cycle and the operation of its components.
A specific data acquisition system with PC based data logging has been developed.
Detailed description of the experimental facilities is given, organized in different sections for the air-handling circuit, the liquid refrigerant circuit, and phase-changing

refrigerant circuit. Subsequently, detailed overview of the measuring instruments is presented, with their accuracies and mounting, respectively for the air, the liquid refrigerant, and the phase-changing refrigerant circuits. Description of the components and parameters of the data acquisition system is given in a final section.

3.2 General description of the experimental facility and the air-handling circuit

This section presents the concept of the experimental infrastructure for testing of air-cooling compact heat exchangers using liquid and phase-changing refrigerants under dry and wet conditions. The whole experimental liquid overfeed system is also presented. The infrastructure consists principally of three circuits described separately in the contiguous sections: the air-handling circuit, the liquid refrigerant circuit, and the phase-changing refrigerant circuit. The air-handling circuit is common part of the facilities for testing of prototypes using liquid and phase-changing refrigerant, and it is described in detail. Each circuit has specific design and independent control. They have the task to assure stable controllable conditions at the inlet of the tested prototype in order to measure its performance.

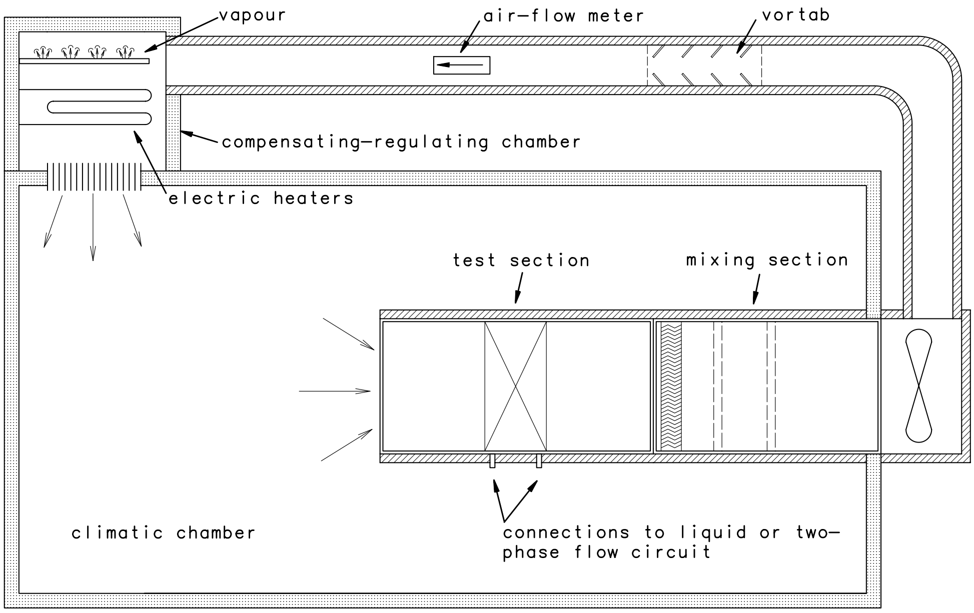

Figure 3.1: Air-handling circuit

The air-handling circuit consists of a climatic chamber connected to a compensating-regulating chamber through an insulated air duct (see Figure 3.1), assuring closed air loop through the tested prototype. The air is aspired from the climatic chamber through the tested heat exchanger by means of a centrifugal fan and is impulsed through the duct to the compensating-regulating chamber, where heat and water vapour are added to it in order to maintain the conditions in the climatic chamber. The air is then returned to the climatic chamber mixed and at low velocity. Two independent controller loops are dedicated to the control of the air temperature and humidity. One of the loops controls electric heaters and the other controls two vapour humidifiers working in a master-slave arrangement, both giving their output in the compensating-regulating chamber.

The test prototype is mounted in the climatic chamber within a thermally insulated duct section, referred to as a test section, that guides the air and facilitates the fitting of the necessary sensors. The test section is tailor-made to fit the specific geometry of the prototype. The test prototype can be optionally connected to the liquid refrigerant circuit or to the phase-changing refrigerant circuit.

The bottom duct wall behind the tested heat exchanger in the test section is perforated with long transversal overlapping slits over the whole width of the duct in order to drain the water condensing over the cold heat exchanger surface and prevent its dragging with the air-flow. The condensate is drained in a tray, welded to the duct wall, and collected for measuring through a syphon (see Figure 3.7).

The test section is coupled to an air-mixing section provided with droplet eliminator and mixers, consisting of two sets of louvers producing a combination of relative displacements of adjacent areas of the air-flow causing horizontal and vertical mixing. It serves to eliminate and collect the condensate drops that could be dragged with the air and to mix the air in order to homogenise the air temperature and prepare it for measurement of the temperature and the relative humidity at the outlet.

The design of the test section and the mixing section permits dry and wet tests (with water vapour condensing over the heat exchanger) to be performed. When wet tests are performed, the condensed water is collected during the test in order to make the appropriate mass and energy balances.

All the variables necessary for the determination of the heat transfer on the air-side are measured. The air mass flow is measured in the duct between the climatic chamber and the compensating-regulating chamber with thermal insertion mass flow-meter. The absolute air pressure inside the climatic chamber is measured with absolute pressure transducer. The air temperature is measured with calibrated thermo-couples type-K distributed in the transversal sections of the duct at the centres of segments of equal cross-sectional area before and after the heat exchanger. The inlet average temperature is obtained from the measurements of the thermo-couples in the inlet section. The outlet average air temperature is obtained from one point measurement of the temperature with a RTD after the mixing section.The measurements of the thermo-couples in the outlet section are used as local temperature experimental data for comparisons with detailed numerical results. The relative humidities at the inlet and outlet are measured with capacitance type sensors at the entrance and after the mixing section. The air pressure loss across the tested prototype is measured with differential pressure transducer. More details about the measuring instruments are given in section 3.5.1.

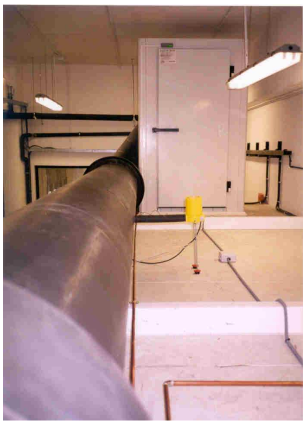

Figure 3.2: Air duct and compens. chamber

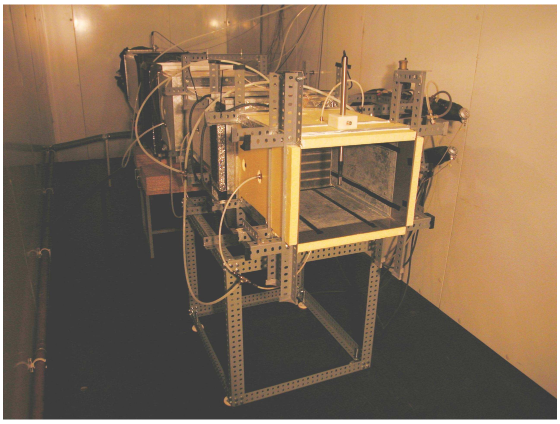

Figure 3.3: Prototype mounting inside climatic chamber

3.3 Liquid refrigerant circuit

The liquid circuit of the experimental facility is designed to assure the adjustment of the desired stable conditions of the liquid refrigerant at the inlet of the tested heat exchanger. This circuit is also used to provide controlled temperature liquid as a secondary fluid in the condenser of the phase-changing refrigerant circuit described in the next section. These objectives have been accomplished by means of two liquid refrigerant loops and a specially designed chiller. A scheme of the set-up is shown in Figure 3.4. The chiller is connected to a thermal storage tank with capacity 500 litres and permits temperatures in the tank between 15^{o}C and -20^{o}C to be maintained. The refrigerant is 50% ethylene glycol-water solution. The primary loop circulates refrigerant from the thermal storage tank through a brazed plate heat exchanger, cooling the secondary loop, where the tested heat exchanger is mounted. Both loops are provided with lobular pumps with variable speed drives.
The flow-rate of the liquid in the test loop is adjusted manually, and the temperature

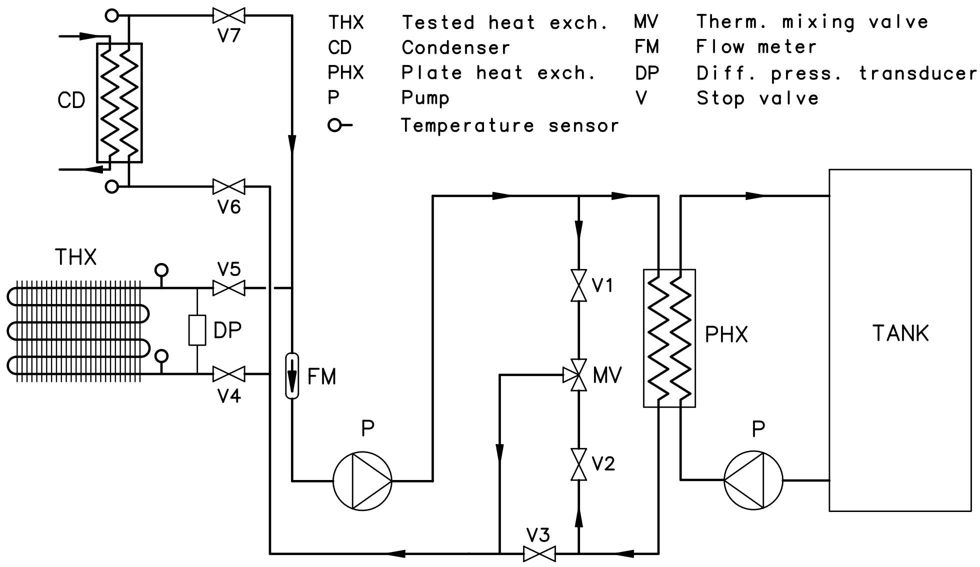

Figure 3.4: Test facility

at the inlet of the tested prototype is adjusted through the temperature in the thermal storage tank and the flow-rate in the primary loop. The control is achieved actuating over the pump speed in the primary loop, controlling thus the heat transfer efficiency between both loops. At this manner precise control of the inlet liquid temperature is achieved, compensating the variation of the temperature in the thermal storage tank. This arrangement gives independence of the test loop and permits different types of refrigerants to be used in the experiments and different flow-rates to be adjusted.
When liquid of the secondary loop is used for cooling the condenser of the liquid overfeed refrigeration system, Figure 3.5, the control strategy is different. The liquid temperature in the secondary loop at this mode is normally high (up to 63^{o}C), while the temperature in the primary loop is limited up to 15^{o}C from the chiller characteristics. With such a large difference the control of the temperature could be achieved with very small flow-rates in the primary loop, which is not appropriate for the pump. The solution of this problem has been the using of thermostatic mixing valve in the secondary loop with regulating range 43^{o}C to 63^{o}C (Sparco Aquamix AM102), by-passing part of the returned flow from the condenser, while the flow-rate in the primary loop is fixed at some convenient level, Figure 3.4. Combination of shut-off valves permits the switching from one mode of control to the other.
The temperatures of the liquid refrigerant at the inlet and outlet of the heat exchanger

are measured with resistance thermal devices (RTD) Pt100, 4 wires. The mass flow of the refrigerant is measured with a Coriolis effect mass flow-meter. The liquid refrigerant pressure loss through the heat exchanger is measured with differential pressure transducer. More detailed information about the measuring instruments is given in the section 3.5.2. The liquid circuit can function in a wide range of temperatures between -18^{o}C and 63^{o}C, with refrigerant mass flow up to 5000 kg/h.

3.4 Phase-changing refrigerant circuit

The phase-changing refrigerant circuit is designed and constructed for experimental studies with the liquid overfeed refrigeration system and the fin-and-tube liquid overfeed evaporator. The tested evaporator prototypes are mounted in the climatic chamber as described in the previous section. The circuit consists of two sub-circuits, sharing some common elements, permitting two different modes of evaporator testing. The first sub-circuit is a complete vapour-compression system with liquid refrigerant overfeed of the evaporator, see [1], [2]. With this system the evaporator is tested as a part of the working refrigeration system. The second sub-circuit is a closed refrigerant loop between the evaporator and the condenser that does not use compressor and is intended for testing only the evaporator. Both sub-circuits permit the control of the desired parameters: liquid refrigerant flow-rate, temperature and pressure at the inlet of the evaporator, and are provided with the necessary instrumentation for determining the cooling capacity of the evaporator and the refrigerant quality at the outlet. The switching from one circuit to another is done with a combination of manual shut-off valves. A scheme of the phase-changing refrigerant circuit is shown in Figure 3.5. The refrigerant lines of the vapour-compression system are represented in the figure with continuous lines. The refrigerant lines of the alternative circuit for testing of the evaporator without compressor are represented with dashed line.

3.4.1 Vapour-compression system circuit

The vapour-compression system is constructed in stainless steel tubes and consists of a semi-hermetic reciprocating compressor, brazed plate liquid cooled condenser, high- and low- pressure receivers, and a fin-and-tube evaporator, over-fed with liquid refrigerant by means of a gear pump. An electronic pulse-width controlled expansion valve (EX2,Alco), with 5 interchangeable orifices permits range of cooling capacities from 1.2 kW to 8.5 kW and assures stable liquid level in the low pressure receiver. The electronic expansion valve is a slide type solenoid valve with an orifice for expansion. It operates with a 6 second pulse width cycle. Partial capacity is achieved proportioning the aperture pulse time relative to 6 seconds. The electronic expansion valve is activated from a controller (Danfoss EKC 347) in a function of the liquid

refrigerant level in the low pressure receiver.
The circulation of the refrigerant through the evaporator is assured by means of a magnetically coupled gear pump (Model 223, Micropump Inc.) with variable speed drive, permitting refrigerant flow-rates up to 700 kg /h.
The system has been designed for continuous operation, and the different operating points could be achieved with a combination of expansion valve orifice, and control over the conditions of the air at the inlet of the evaporator and of the secondary fluid in the condenser. The evaporating temperature could be adjusted in the range of -20^{o}C to $+15^{o}$C.
In this mode of working the compressor sucks saturated vapour from the low-pressure receiver. The compressed refrigerant vapour is discharged to the condenser where liquifies and passes through the receiver to the electronic expansion valve. Here the refrigerant pressure is reduced and the refrigerant enters the low-pressure receiver, where the liquid and vapour phases are separated. The liquid refrigerant is recirculated from the low-pressure receiver through the evaporator by means of the gear pump. The evaporated refrigerant is directed to the compressor, thus closing the refrigeration cycle.
A highly efficient coalescing filter oil separator (assuring 10 ppm oil content after it) is installed in the discharge line of the compressor to minimize the quantity of oil entering the system. Nevertheless, with time, a small quantity of oil could pass to the system's low pressure side and accumulate there. Therefore, additional refrigerant line must assure the oil return from the low pressure side to the compressor. A small quantity of refrigerant is taken from the liquid line feeding the evaporator using metering valve and completely evaporated versus hot water in a small plate heat exchanger. The refrigerant vapour and the contained oil are returned to the compressor introducing them into the suction line. This additional oil return line is closed when tests are performed in order energy balances over the system to be made in a straightforward manner.

3.4.2 Circuit without compressor

This circuit permits testing the evaporator separately of the refrigeration system, without using the compressor. It shares with the first system the evaporator, the condenser, the receiver and the gear pump. The circuit represents a closed refrigerant loop between the evaporator, the condenser and the receiver. The circulation of the refrigerant is assured with the gear pump. This circuit is shown in Figure 3.5, where the refrigerant lines are represented with dashed lines.
The liquid refrigerant is circulated from the receiver through the evaporator, where is partially evaporated. The liquid-vapour refrigerant mixture leaving the evaporator is sent to the condenser, where liquifies and enters the receiver, thus closing the loop. The receiver serves as an accumulator to accommodate the liquid volume variations in

the evaporator and the connecting lines for the different working points, maintaining stable positive suction pressure for the pump. The whole circuit is well insulated, so that the heat exchange is produced only in the evaporator and the condenser. The adjustment of the evaporating temperature is done through the temperature of the secondary cooling fluid in the condenser using the liquid circuit described in the previous section.
The accumulation of liquid in vertical risers of two-phase flow above the evaporator creates static pressure resulting in elevation of the evaporating pressure and temperature, penalizing evaporator's performance. This problem have been resolved with the use of a 3 m high triple vertical riser in the line connecting the evaporator and the condenser. A combination of shut-off valves permits the adjustment of the upward two-phase flow in the optimal regime, minimizing the penalty of the evaporating temperature [1], [3].
In the vapour compression cycle the working range of the system is limited by the characteristics of the compressor and this also imposes limitations for the evaporator testing. Only limited range of cooling capacities and evaporating temperatures for a given prototype is allowed.
The alternative direct connection between the evaporator and the condenser gives the possibility to decouple the working range of the evaporator from the compressor limitations and the working range is only limited by the maximum capacity of the refrigeration machine connected to the liquid circuit, and the available ranges of refrigerant and air flow-rates. This arrangement considerably expands the capabilities of the experimental facility for testing liquid overfeed evaporators.

Component	**Model**	**Manufacturer**
Reciprocating compressor	AM2/121-4S	Bock Kältemaschinen
Brazed plate condenser	NB51	Alfa Laval
Magnetically coupled gear pump	Model 223	Micropump Inc.
Electronic expansion valve	EX2	Alco, Emerson Corp.
Liquid level controller	EKC 347	Danfoss

Table 3.1: Principal components of the phase-change refrigerant circuit

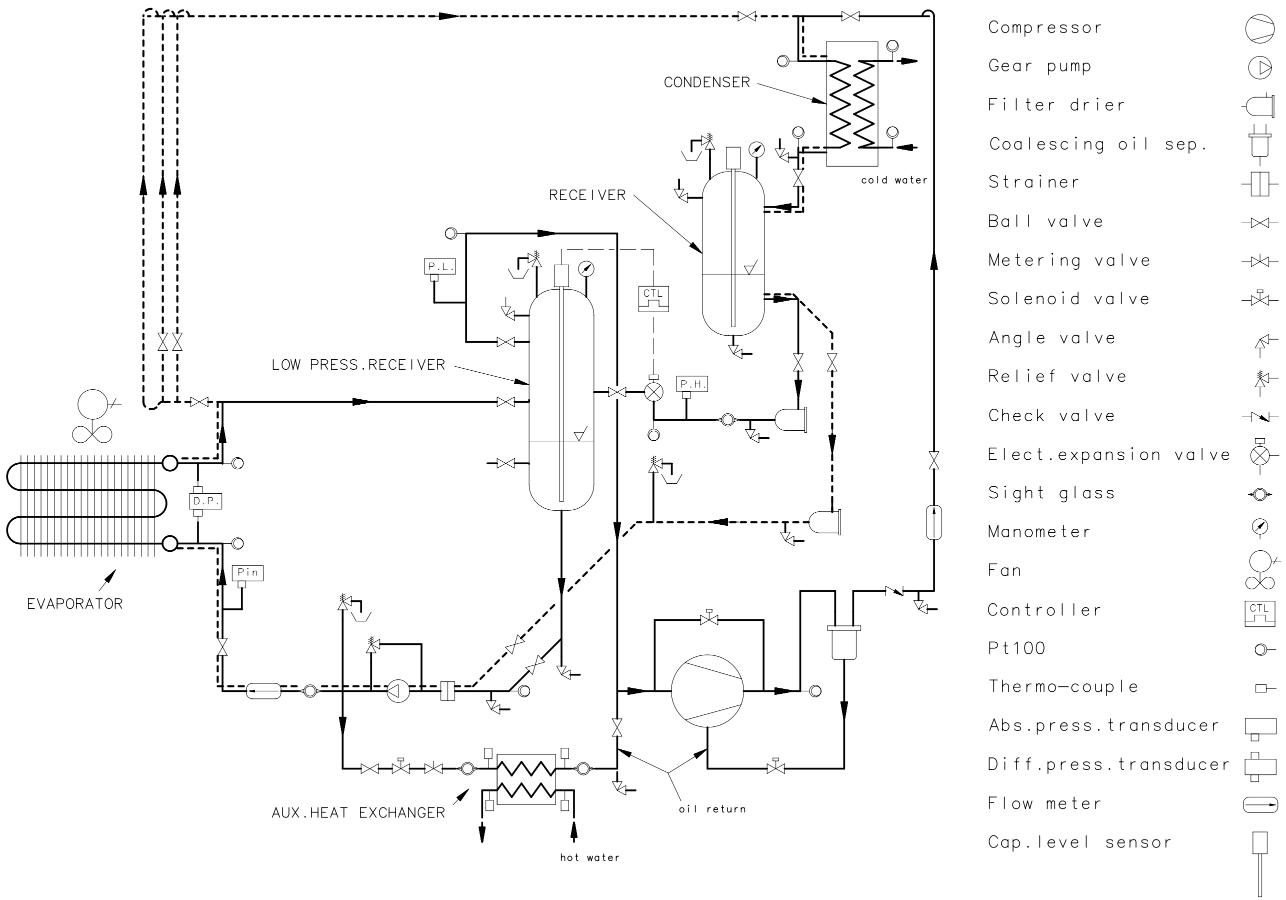

Figure 3.5: Scheme of the phase-changing refrigerant circuit

Figure 3.6: Phase-changing refrigerant circuit: Views of the outside circuit with low-pressure receiver, compressor, pump, etc. View of the evaporator connection.

3.5 Instrumentation and measuring

The instrumentation used in the experimental facilities has been selected and applied for the measuring of all the variables necessary for determining the performance of the studied heat exchangers and the liquid overfeed refrigeration system. It assures reliability and acceptable accuracy of the measurements, corresponding to the level of detail and accuracy of the numerical simulations to which validation is intended. Diverse instruments have been used depending on the particular application and measurand characteristics, considering always their capability for automated data acquisition.
Detailed description of the used measuring instruments and comments for their application in the facility are presented subsequently, organized separately for the air-handling circuit, the liquid refrigerant circuit, and the phase-changing refrigerant circuit.

3.5.1 Air-handling circuit instrumentation

The measuring instruments in the air-handling circuit give the necessary experimental data for determining the tested prototype's cooling capacity and the air pressure drop through it. The dry bulb air temperatures and the relative humidities at the inlet and outlet of the prototype, the air mass flow, the inlet absolute air pressure and the air pressure loss are measured. In the case of wet tests, the water condensate over the tested heat exchanger surface is measured and incorporated in the energy balance. The physical location of the sensors is shown in Figure 3.7.
The air temperature is measured with calibrated thermo-couples type-K distributed in the transversal sections of the duct at the centres of segments of equal cross-sectional area before and after the heat exchanger. From this measurements the average air temperatures can be estimated. Averaging the temperatures measured with the thermo-couples in such a manner gives the correct average air temperature only if the air velocity is the same for each area. Because of the stable control and the temperature uniformity in the climatic chamber, the inlet average temperature is obtained from the measurements of the thermo-couples in the inlet section as an algebraic mean. In order to obtain confident average air temperature at the outlet, where non-uniformity of the temperature is created after the heat exchanger, one point measurement of the temperature is done with RTD after the mixing section (see Figure 3.7). The measurements of the thermo-couples in the outlet section are used as local temperature experimental data for comparisons with detailed numerical results from the heat exchanger model.
The relative humidity (RH) at the inlet and outlet is measured with capacitance type sensors, model HygroClip, Rotronik incorporating RTD for temperature measurement, at the entrance and after the mixing section. During wet tests the condensate

is measured. Due to the accuracy decrease of the capacitance type relative humidity sensors in near saturation conditions (RH$\geq$ 90%), in this cases the relative humidity at the outlet is calculated from the relative humidity at the inlet, the condensed flux, and the temperatures at the inlet and outlet using psychrometrical relations.
The air mass flow is measured in the duct between the climatic chamber and the compensating-regulating chamber with thermal insertion mass flow-meter FlexMASSter model ST95, Fluid Components Intl. Ltd., as shown in Figure 3.1. The instrument is factory calibrated together with a flow homogenizing insertion sleeve VORTAB, placed at an exact distance before the flow-meter.
The absolute air pressure in the climatic chamber is measured with absolute pressure transducer 3051TA, Rousemount Inc.
The pressure loss air-side is measured with differential pressure transducer 3051CD, Rousemount Inc. The pressure is taken from four small taps situated in the transversal section of the air duct, in the centre of the duct walls. The pressure taps are connected to an equalizing piezometric ring, before and after the heat exchanger, as proposed by Benedict [4], shown in Figure 3.8.

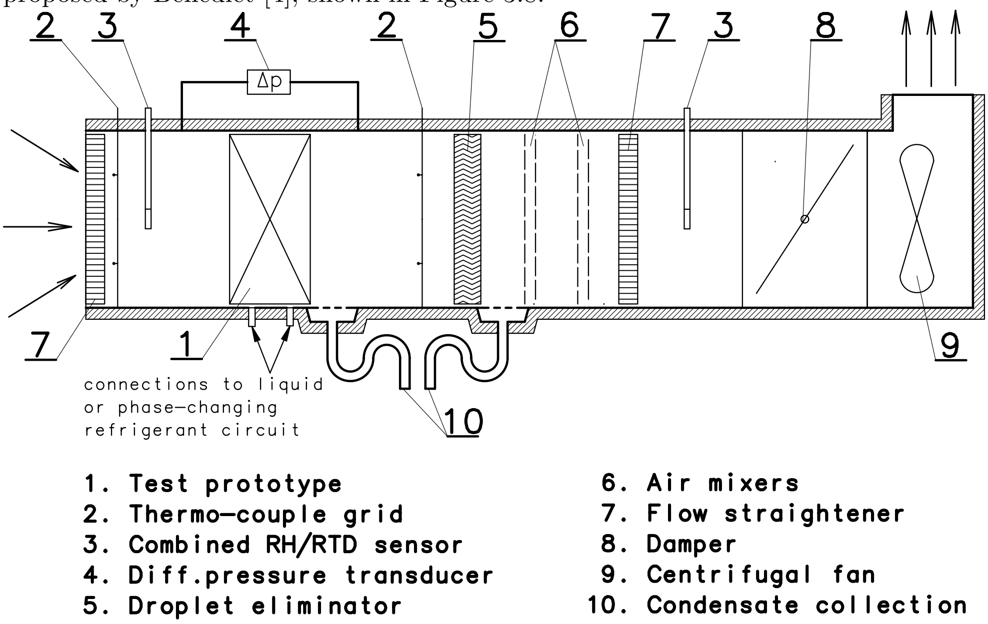

Figure 3.7: Test section air-side

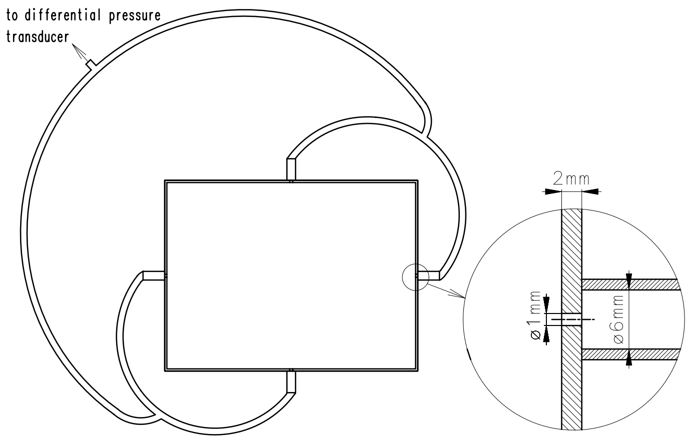

Figure 3.8: Equalizing piezometric ring

The temperature and the relative humidity in the climatic chamber are controlled from PID controller (Eurotherm 2604) using as an input the measurement of the combined temperature/RH sensor HygroClip (Rotronik), actuating over electric heaters and vapour humidifiers, giving their output in the compensating-regulating chamber.
The accuracies of the measuring instruments in the air loop are given in Table 3.2. The accuracy of the temperature sensors (thermo-couples and RTD) are evaluated experimentally following the procedure described in section 4.3 Calibration and test procedures. The accuracy of the water condensate measurement is evaluated from the resolution of the measuring container and experimental tests. The stated accuracies of the rest of instruments are based on manufacturer data.

Instrument	Accuracy
Air loop	
Temperature: thermo-couple type K	$\pm 0.3[C]$
Relative humidity	$\pm 2[\%]$
Temperature: RTD, Pt100	$\pm 0.08[C]$
Air flow	$\pm 2[\%]$ of reading
Water vapour condensate	$\pm 0.040[kg]$ for test
Differential pressure	$\pm 2.55[Pa]$ ($\pm 0.51[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)
Absolute pressure	$\pm 300[Pa]$ ($\pm 0.3[\%]$ of full scale)

Table 3.2: Accuracies of the measuring instruments in the air-handling circuit

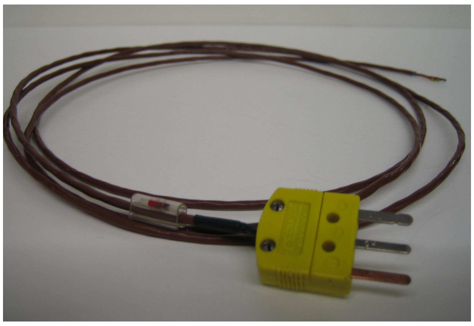

Figure 3.9: Thermo-couple type-K

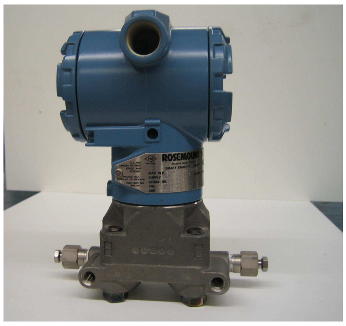

Figure 3.10: Differential pressure transducer

Figure 3.11: RH sensor

Figure 3.12: Air mass flow-meter

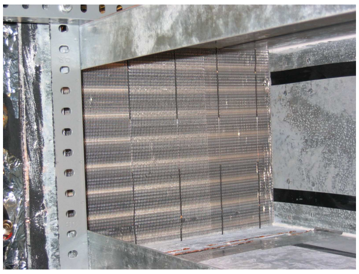

Figure 3.13: Thermo-couple grid mounting

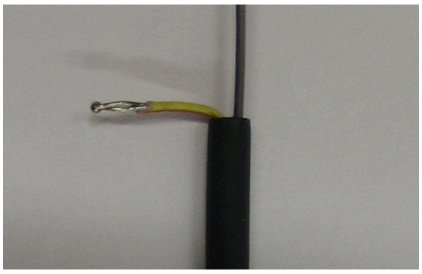

Figure 3.14: Thermo-couple detail

3.5.2 Liquid refrigerant circuit instrumentation

The measuring instruments in the liquid refrigerant circuit permit the determining of the cooling capacity and the pressure drop of the tested prototype on the liquid-side. The inlet and outlet refrigerant temperatures are measured with four wire resistance thermal devices (RTD, Pt100). The sensors are mounted in well insulated T-connections, downstream of a flow turn assuring fluid mixing.
The mass flow of the refrigerant is measured with a Coriolis effect mass flow-meter Promass 60 F, Endress+Hauser Flowtec AG. The flow-meter is mounted in a vertical position with the flow upwards, following manufacturer's instructions. This keeps the measuring tubes clean from possible solid impurities build-up and prevents gas accumulation when fluid is not flowing.
The liquid refrigerant pressure loss through the heat exchanger is measured with differential pressure transducer 3051CD, Rosemount Inc. The pressure is taken from small holes at the inlet and outlet of the prototype, after a straight section (approx. 10 times tube inlet diameter), serving for uniform flow development. Optional connections provided with shut-off valves permit the measurement of the liquid pressure loss through a single circuit of the tested prototype with the same instrument (see Figure 3.15).

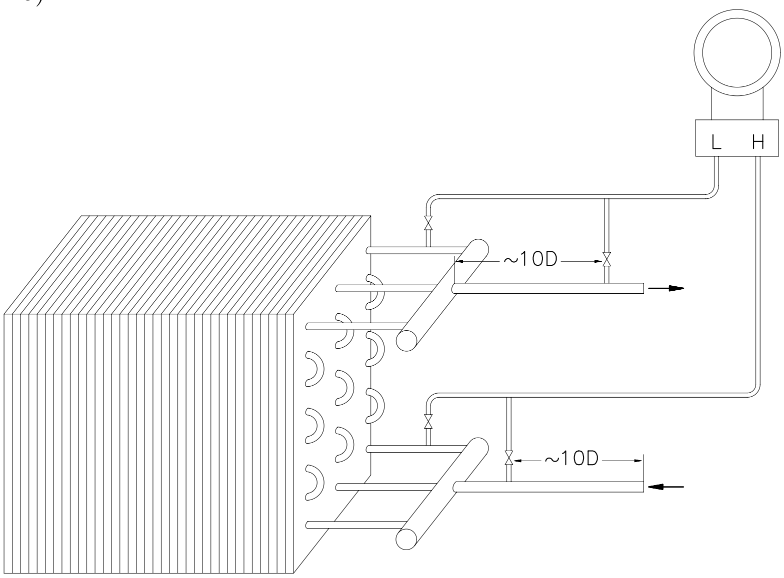

Figure 3.15: Connection of the differential pressure transducer

The liquid refrigerant temperature control at the inlet of the tested compact heat exchanger is assured with a PID controller (Eurotherm 2604), actuating over the pump speed in the primary circuit (see section 3.3). The input signal for the temperature control is provided from additional RTD, mounted in the refrigerant feeding line. In the case of using the liquid circuit for cooling the condenser in the phase-changing refrigerant circuit (section 3.4), the control is done by means of a thermostatic mixing valve.
The accuracies of the measuring instruments used in the liquid circuit are given in Table 3.3. The temperature sensors (RTD) are calibrated in the CTTC versus precision thermometer with accuracy $\pm 0.03^{o}$C, and their uncertainties are determined with the experimental procedure described in section 4.3. The refrigerant flow-meter and the differential pressure transducer are factory calibrated to the experimental range, and the stated accuracies are based on manufacturer calibration certificates.

Instrument	**Uncertainty**
Liquid loop	
Temperature: RTD, Pt100	$\pm 0.08[C]$
Refrigerant flow	$\pm 1[\%]$ of reading
Differential pressure	$\pm 375[Pa]$ ($\pm 0.15[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)

Table 3.3: Accuracies of the measuring instruments in the liquid circuit

Figure 3.16: Resistance thermal device, Pt100

Figure 3.17: Liquid mass flow-meter

3.5.3 Phase-changing refrigerant circuit instrumentation

The phase-changing refrigerant circuit is extensively instrumented with different sensors quantifying the physical variables during the tests and permitting the determining of the cooling capacity refrigerant-side. Temperatures and absolute pressures in various points are measured in the high and low pressure circuits of the liquid overfeed refrigeration system. The mass flow-rates of the refrigerant through the compressor and the evaporator, and the mass flow-rate and temperatures of the secondary fluid in the condenser are measured, as can be seen in Figure 3.5.

The temperatures are measured with four wire RTD, Pt100. The absolute pressure of the refrigerant at the inlet of the evaporator is measured with precision pressure transducer type PMP4070, Druck Limited. The absolute pressure is also measured in the suction line of the compressor near the low pressure receiver, and in the high pressure liquid line before the expansion valve with absolute pressure transducers 3051TA, Rosemount Inc. The mass flow through the compressor is measured with Coriolis mass flow-meter Promass 80 F, Endress+Hauser Flowtec AG. The refrigerant flow through the evaporator is measured with Coriolis mass flow-meter RHM06, Rheonik Messgeraete GmbH. The liquid level in the receiver and the low pressure receiver are measured with capacitance type level sensors Techni-Level, Hansen Technologies Corp.

The pressure drop through the evaporator is measured with differential pressure transducer 3051CD, Rosemount Inc. This measurement has suggested an arrangement problem. The inlet refrigerant is liquid and the outlet refrigerant is liquid and vapour mixture. The pressure connections of the transducer to the process could be partially filled with liquid and vapour. The unknown liquid column in the pressure connections can exert static pressure, affecting thus the measurement of the pressure difference between the inlet and outlet. In heavy refrigerants as R134a this could be in the order of the measurement itself. This problem have been resolved elevating the inlet liquid refrigerant line at the same height as the outlet line of the evaporator and making the high- and low-pressure connections

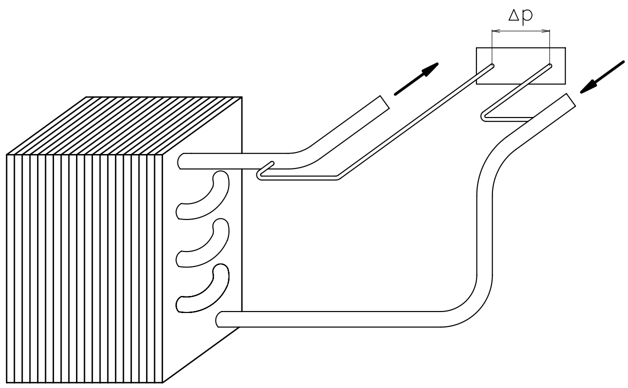

Figure 3.18: Connection of the differential pressure transducer to the evaporator

to the differential pressure transducer at the same height, carrying them horizontally to the transducer as shown in Figure 3.18. This arrangement eliminates the influence of the connecting tubes in the measurement. The measured pressure loss includes the portion of the inlet liquid line between the inlet pressure take and the inlet of the evaporator.
The accuracies of the measuring instruments in the phase-changing circuit are given in Table 3.4. The temperature sensors (RTD) are calibrated in the CTTC according to an established experimental procedure (see section 4.3). The rest of the instruments are factory calibrated, and the stated accuracies are based on the manufacturers calibration certificates.

Instrument	**Uncertainty**
Refrigerant R134a circuit	
Temperature: RTD, Pt100	$\pm 0.08[C]$
Refrigerant flow evaporator	$\pm 1[\%]$ of reading
Refrigerant flow compressor	$\pm 1[\%]$ of reading
Differential pressure	$\pm 94[Pa]$ ($\pm 0.15[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)
Absolute pressure evap. inlet	$\pm 280[Pa]$ ($\pm 0.04[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)
High absolute pressure	$\pm 4500[Pa]$ ($\pm 0.15[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)
Low absolute pressure	$\pm 1125[Pa]$ ($\pm 0.15[\%]$ of full scale incl. amb. temp. var.$\pm 10[C]$)
Liquid level	$\pm 2[\%]$ of full scale
Secondary fluid to condenser loop	
Temperature: Pt100	$\pm 0.08[C]$
Refrigerant flow	$\pm 1[\%]$ of reading

Table 3.4: Accuracies of the measuring instruments in the phase-changing circuit

Photos of some of the instruments used in the phase-changing circuit are presented.

Figure 3.19: Absolute refrigerant pressure transducer

Figure 3.20: RTD Pt100 mounting in a bend

Figure 3.21: Liquid refrigerant mass flow-meter: transmitter

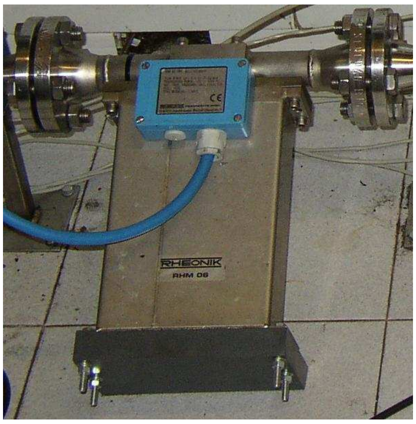

Figure 3.22: Liquid refrigerant mass flow-meter: sensor

Figure 3.23: Vapour refrigerant mass flow-meter

Figure 3.24: Refrigerant liquid level transducer

3.6 Data acquisition system

The data acquisition system is based in Hewlett Packard HP34970A data acquisition units. Each unit is provided with 3 connectable modules (multiplexors) permitting the exploration and direct measurement of temperature, tension and resistance. The multiplexor permits the measurement of 20 thermo-couples, 20 DC voltage signals, or 10 four-wire resistance measurements. It is provided with an isothermal block to minimize the errors derived from temperature gradients in measurements with thermo-couples. A sensor measuring the isothermal block's temperature is used as a reference for the thermo-couple temperature measurements. The accuracy of the acquisition system is $\pm 0.2^oC$ for thermo-couple type-K measurements and $\pm 0.06^oC$ for Pt100 temperature measurement. The accuracy in the measurement of voltage DC is $\pm$(0.0035% of reading + 0.0005% of scale).
The data acquisition system is connected to a PC with a GPIB IEEE488 bus, and all the data is recorded for further processing.

3.7 Conclusions

An experimental infrastructure has been designed and constructed with the objective of experimental validation of numerical models in the field of refrigeration and air conditioning. The infrastructure consists of a climatic chamber, a liquid refrigerant circuit for testing of air-cooling fin-and-tube heat exchangers, and a phase-changing circuit with R134a refrigerant, permitting experiments with the overfeed evaporator itself or with the whole liquid overfeed refrigeration system. The climatic chamber assures controlled conditions (temperature and humidity) of the air-flow through the tested heat exchangers, which can be optionally connected to the liquid refrigerant or the phase-changing refrigerant circuits. The liquid refrigerant circuit is capable to provide liquid refrigerant at controlled temperature and flow-rate through an arrangement of two refrigerant loops transferring heat by means of a brazed plate heat exchanger. The test loop is independent, which permits experiments with different refrigerant fluids to be performed. The phase-changing refrigerant circuit constitutes a vapour-compression refrigeration system with mechanical liquid overfeed of the evaporator and water cooled condenser. An alternative direct connection between the evaporator and the condenser permits the testing of liquid overfeed evaporators in ranges outside the working range of the compressor.
The experimental facilities are extensively instrumented with sensors quantifying all the variables necessary to determine the heat transfer in the tested heat exchangers, the components of the liquid overfeed refrigeration system, and the characterization of the vapour-compression cycle. The experimental measurements are recorded on a PC, using specially developed data acquisition system.

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