6th International Congress on

GREEN PROCESS ENGINEERING

GPE

3 - 6 June 2018

TOULOUSE
France

XERIC

INNOVATIVE CLIMATE-CONTROL SYSTEM TO EXTEND RANGE OF ELECTRIC VEHICLES AND IMPROVE COMFORT

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European Commission

H2020 - GV - 2014 / GV - 2 - 2014 / RIA n° 653605

Keynote Lecture

THE 3-FLUIDS COMBINED MEMBRANE CONTACTORS AS NEW CLIMATE-CONTROL UNITS FOR MORE ENERGY-EFFICIENT ELECTRIC VEHICLES: AN OUTLINE OF H2020 XERIC PROJECT

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Presented by

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Université de Lorrraine, France

XERIC SAB Member

ENERGY SUPPLY FOR INTENSIFIED PROCESSES
Thesis Room
Présidence: Denis Bouyer

14:00 - 14:30

Summary of the lecture

I. Brief introduction
II. XERIC system
III. Some insights into the project & main results
IV. Comments & conclusions
V. Q&A

What is XERIC?

- **EC-funded** project
- Start: June 1, **2015**
- End: May 31, **2018**
- **8** partners + **1** third party

Aim

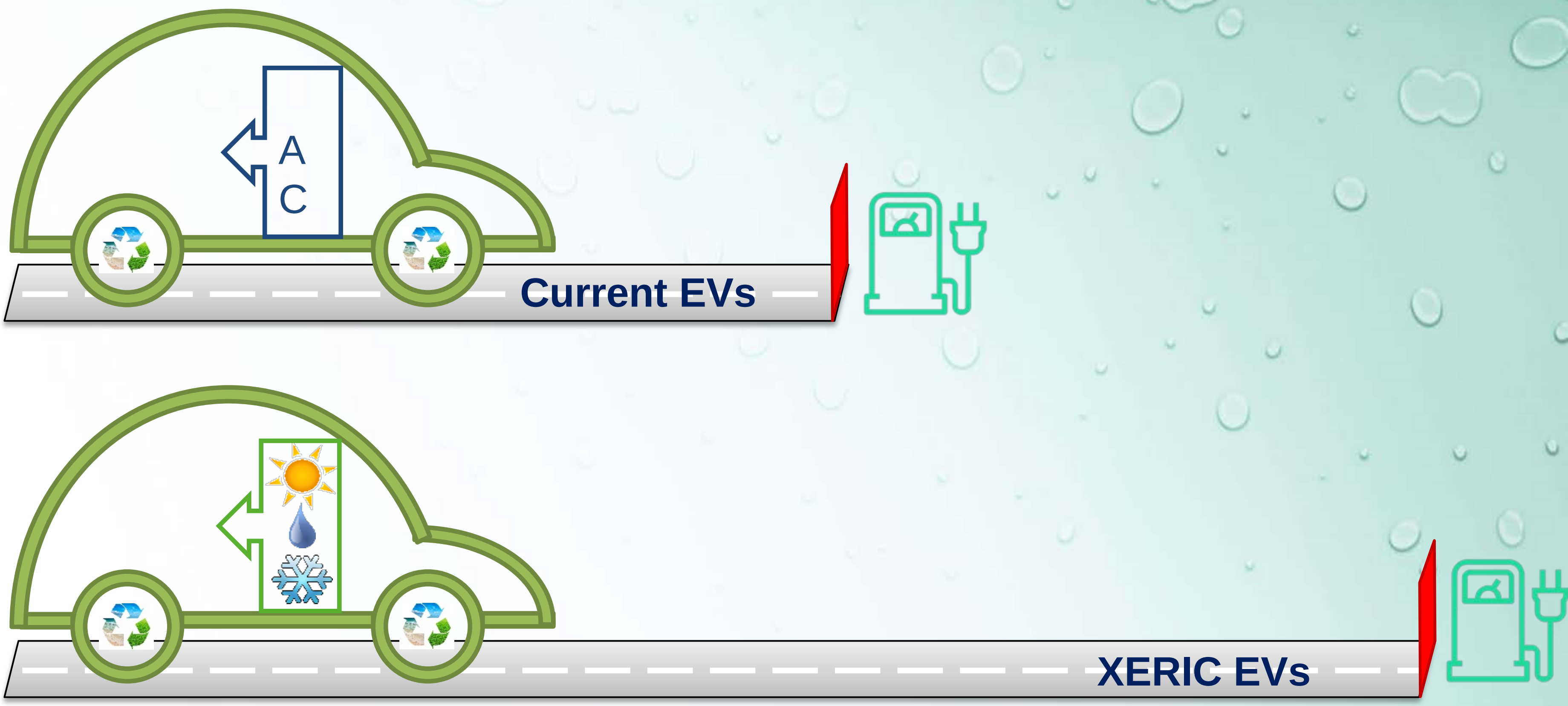
Developing an **energy-friendly climate-control system** for electric vehicles capable of reducing the yearly energy used for AC of at least 50%.

How ?

By building a **novel 3F – CMC contactor (gas – liquid)**

www.xeric.eu

XERIC at a glance



XERIC - Innovative Climate-Control System to Extend Range of Electric Vehicles and Improve Comfort

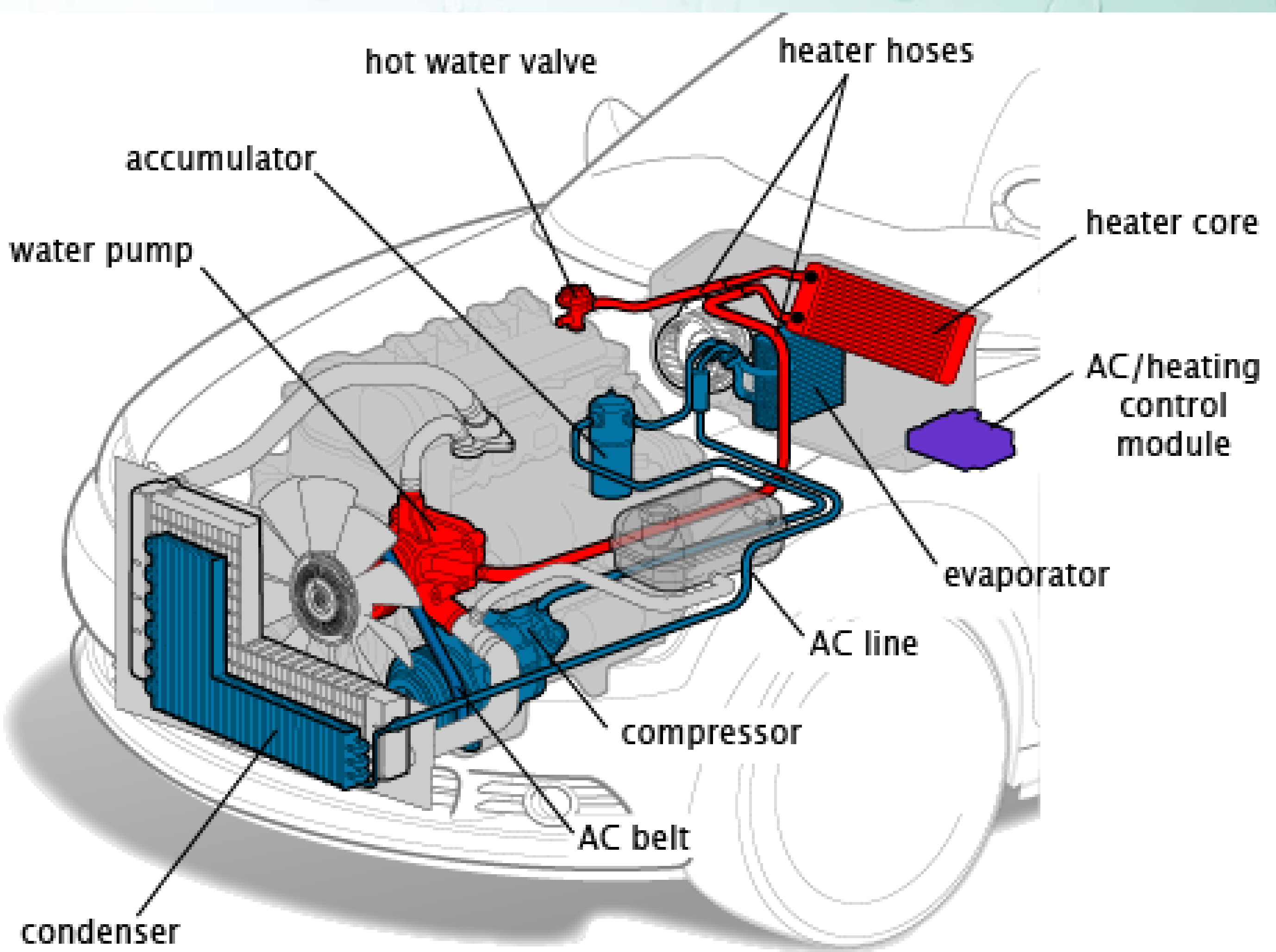
Main target: development of a small-scale prototype of an energy-saving climate control system for EVs currently on the market.

Goals:

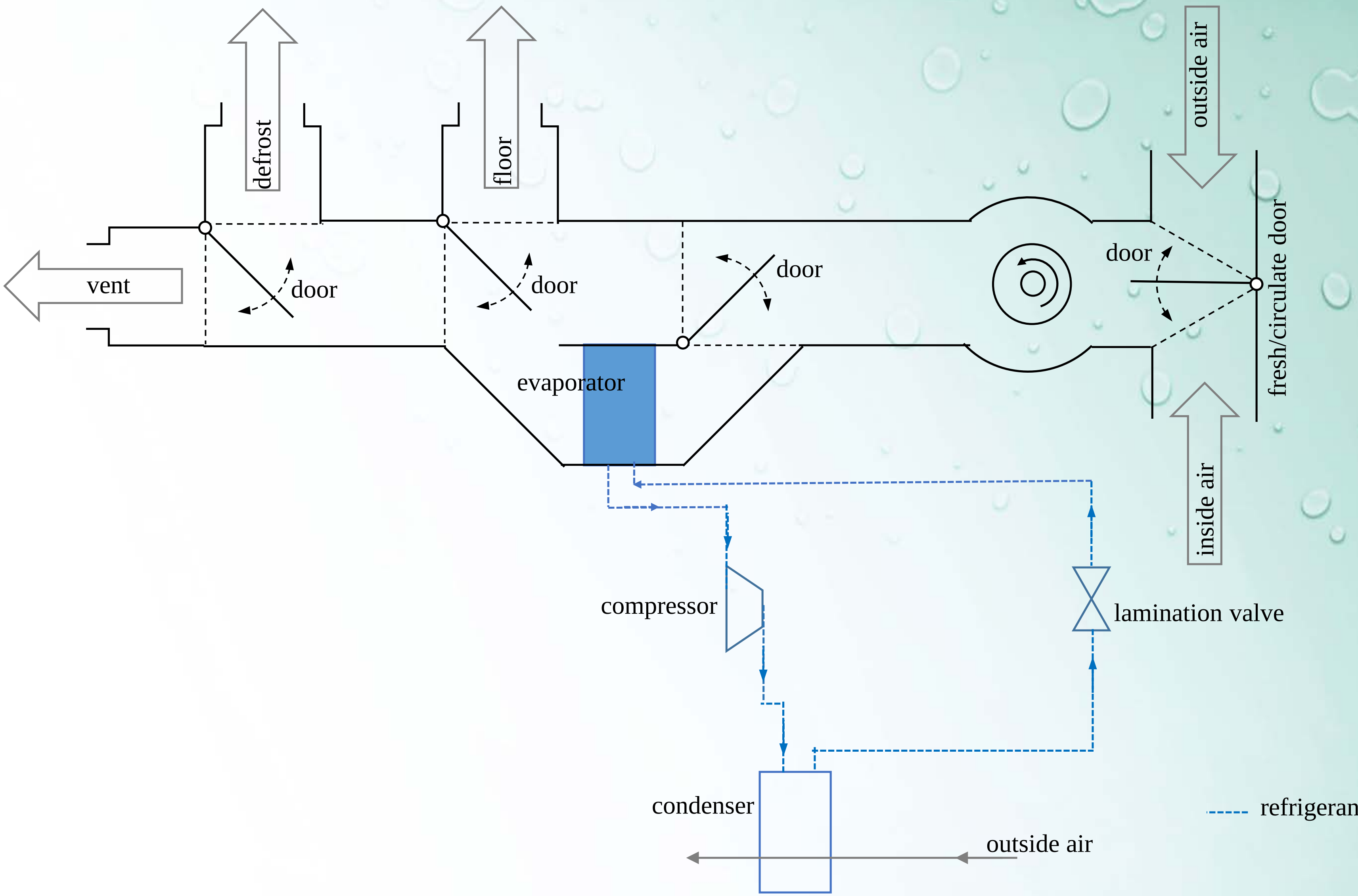
1. reduce more than 50% the energy used all over the year for heating, cooling and dehumidifying air compared to existing systems*;
2. reduce more than 30% the energy used for air cooling/dehumidifying in extreme summer conditions (i.e., external air at T=30 °C and RH=60%) to guarantee comfort in the passenger cabin (i.e., T≈25 °C and RH≈50%);
3. guarantee the after-project easy industrial scale-up and the customization of system;
4. guarantee an adequate working life;
5. withstand the different external air temperature ranges across Europe;
6. profitably use the components currently installed in EVs;
7. guarantee a reasonable cost (to OEM), which depends mainly on car size, when produced at industrial level.

*up to 2014; an usual AC cycle and direct electric heating are considered for comparison.

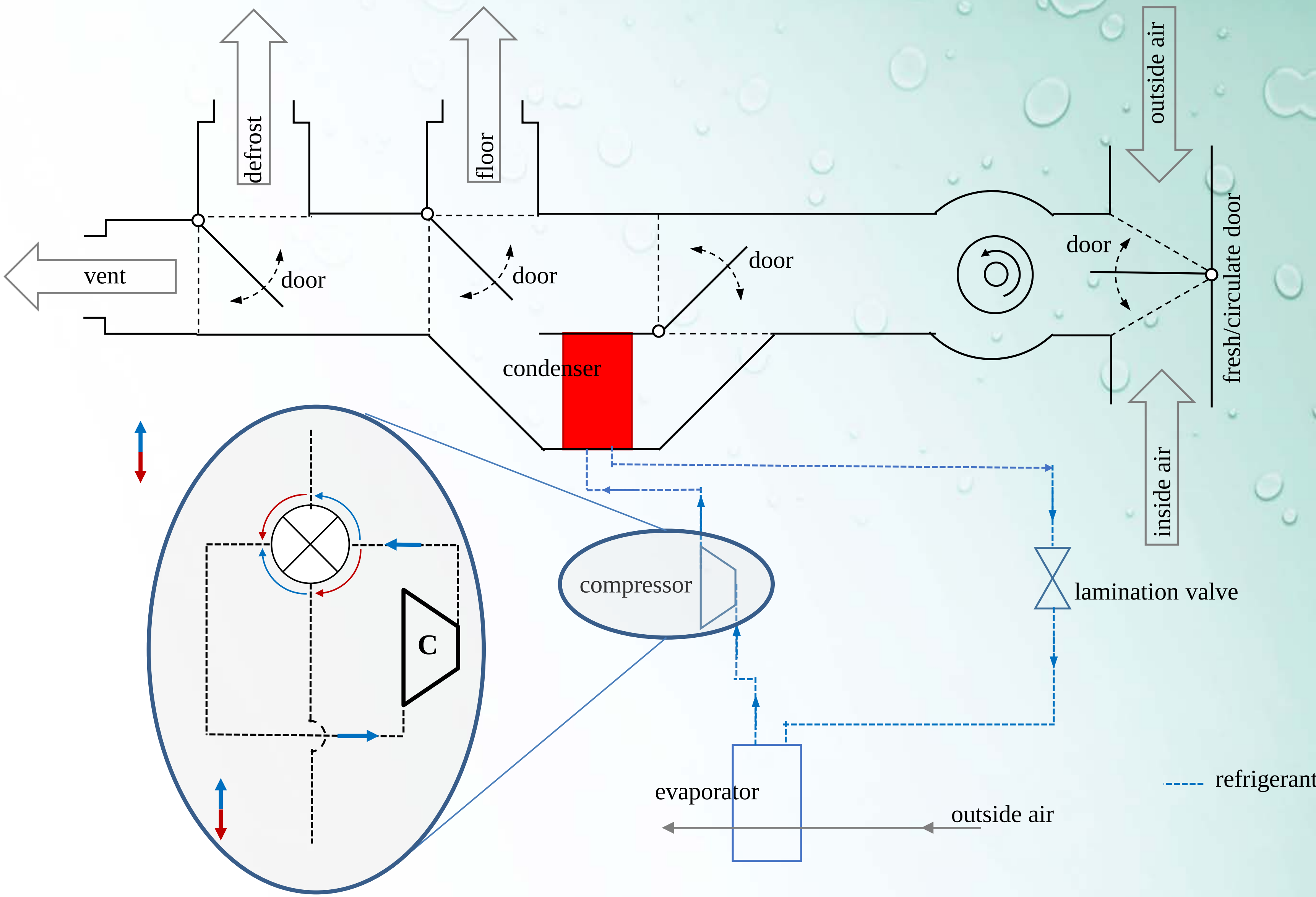
Air-Conditioning System in ICE cars: Vapour Compression Cycle (VCC)



EV cars: system architecture in summer conditions



EV cars: heat pump system architecture in winter conditions



XERIC AC SYSTEM

Traditional Vapour Compression Cycle (VCC), which cools the air

+

Liquid desiccant cycle, which dehumidifies the air

Why XERIC system is so attractive to EV cars?

Since it allows:

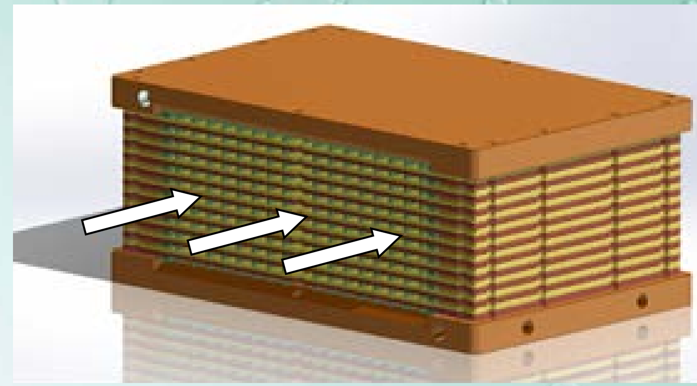
- separate air-dehumidification and air-cooling processes (no need for under-cooling) → energy savings;
- development of tailored systems (thanks to the flexibility given by modularity) → several potential fields of application.

Key player: the innovative and patented Three Fluid Combined Membrane Contactors (3F-CMCs) working simultaneously with air, liquid desiccant and refrigerant.

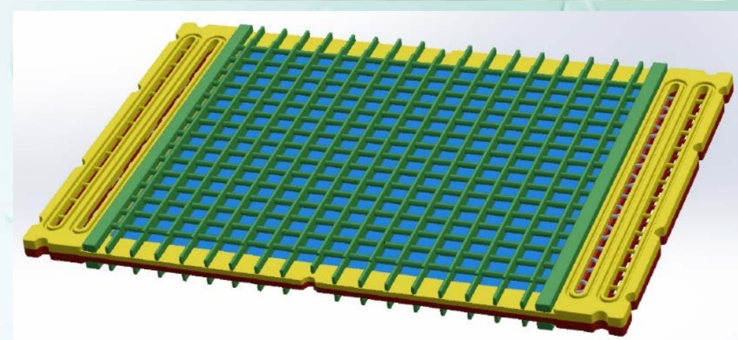
Currently, the adopted refrigerant is R134a and the chosen liquid desiccant is a LiCl aqueous solutions with a 20-30 % salt mass composition.

The innovative 3F-CMC

The 3F-CMC is a three-fluids heat and mass exchanger, where air is dehumidified and cooled by a liquid desiccant solution and a refrigerant, respectively.



Base module:
1 Male frame
1 Female frame
2 sheets of membrane
4 U-shaped minitubes
1 spacer
gasket sealings

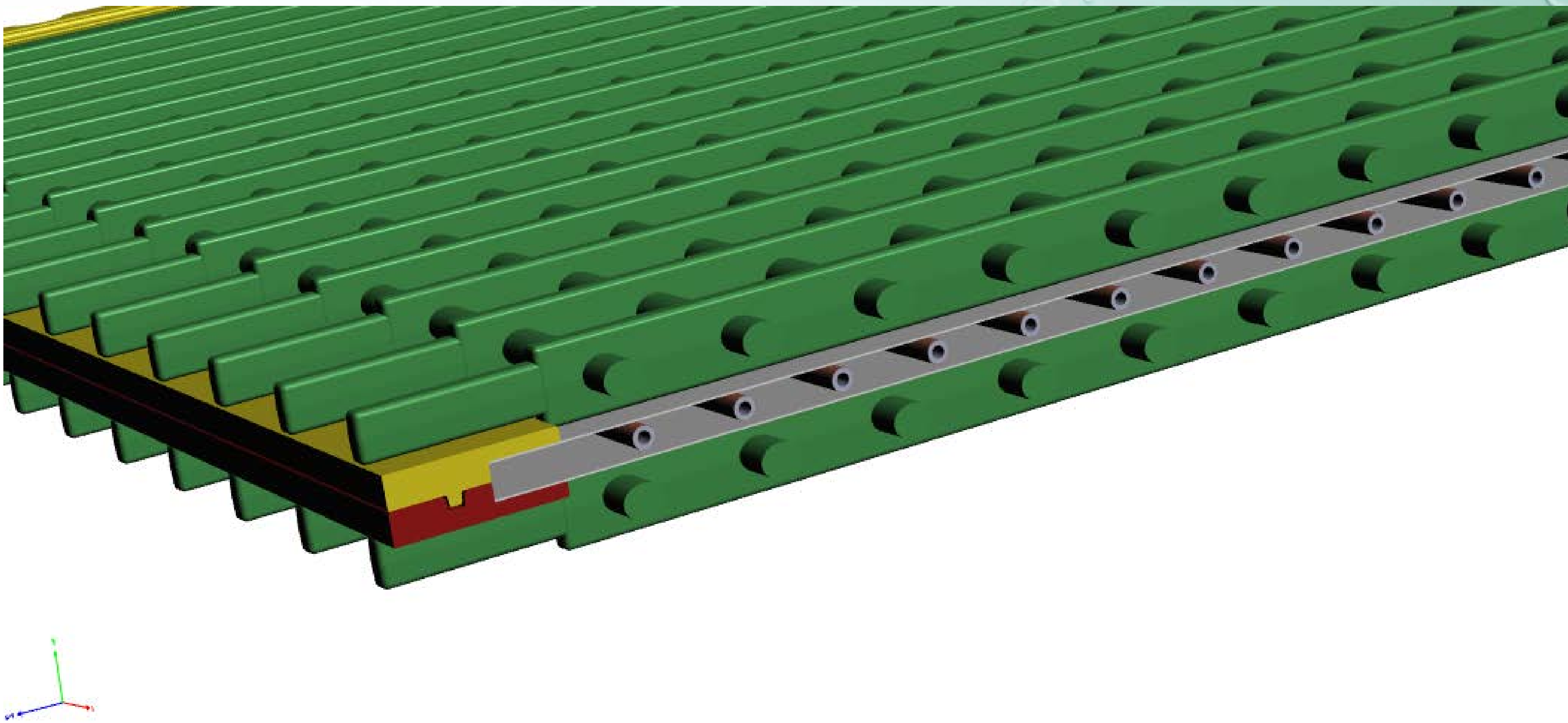


Core of the 3F-CMC is a semi-permeable membrane.

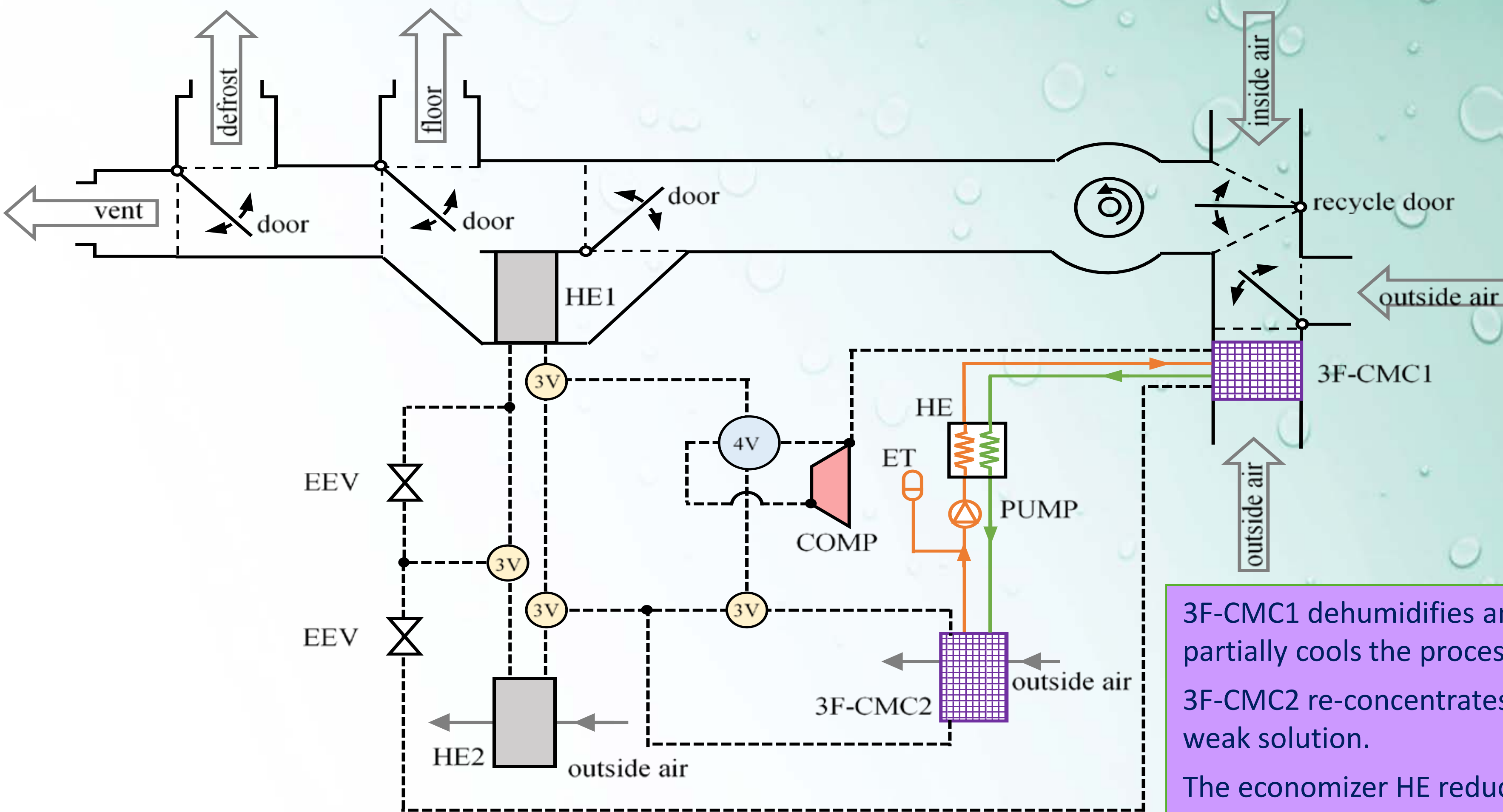
Main advantages:

- ➢the heat exchange between the desiccant and the refrigerant allows the desiccant temperature to be controlled throughout all the 3F-CMC;
- ➢high efficiency and compactness (i.e., increase in sensible and latent heat loads that can be faced).

Details of 3F-CMC



XERIC system architecture



3F-CMC1 dehumidifies and partially cools the process air.

3F-CMC2 re-concentrates the weak solution.

The economizer HE reduces parasitic heat transfer.

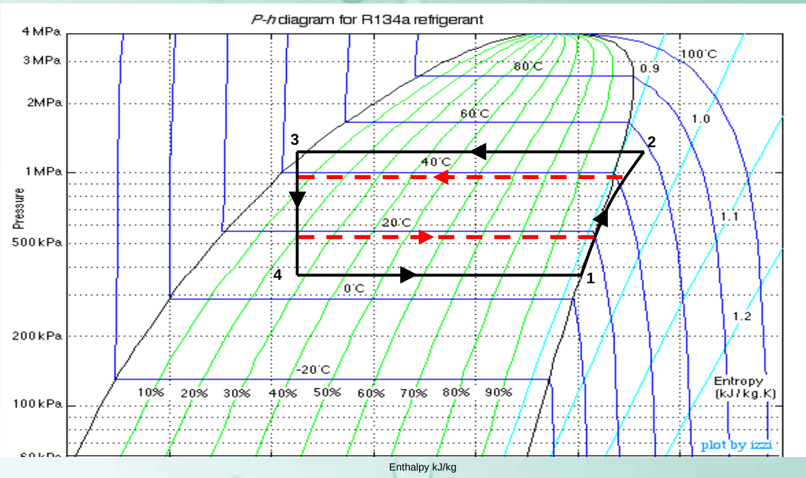
Concentrated warm desiccant
Diluted cold desiccant

HE	Heat exchanger
3F-CMC	Three-fluids combined membrane contactor
3V	Three-way valve
4V	Four-way valve
ET	Expansion tank
COMP	Compressor
EEV	Electronic-controlled expansion valve

XERIC's energy efficiency throughout the year

- Summer and intermediate seasons:

  XERIC system allows the VCC to operate at higher evaporation temperature and lower condensation temperature.



- Raining days:

  XERIC system allows dehumidification only, with a small cooling effect.

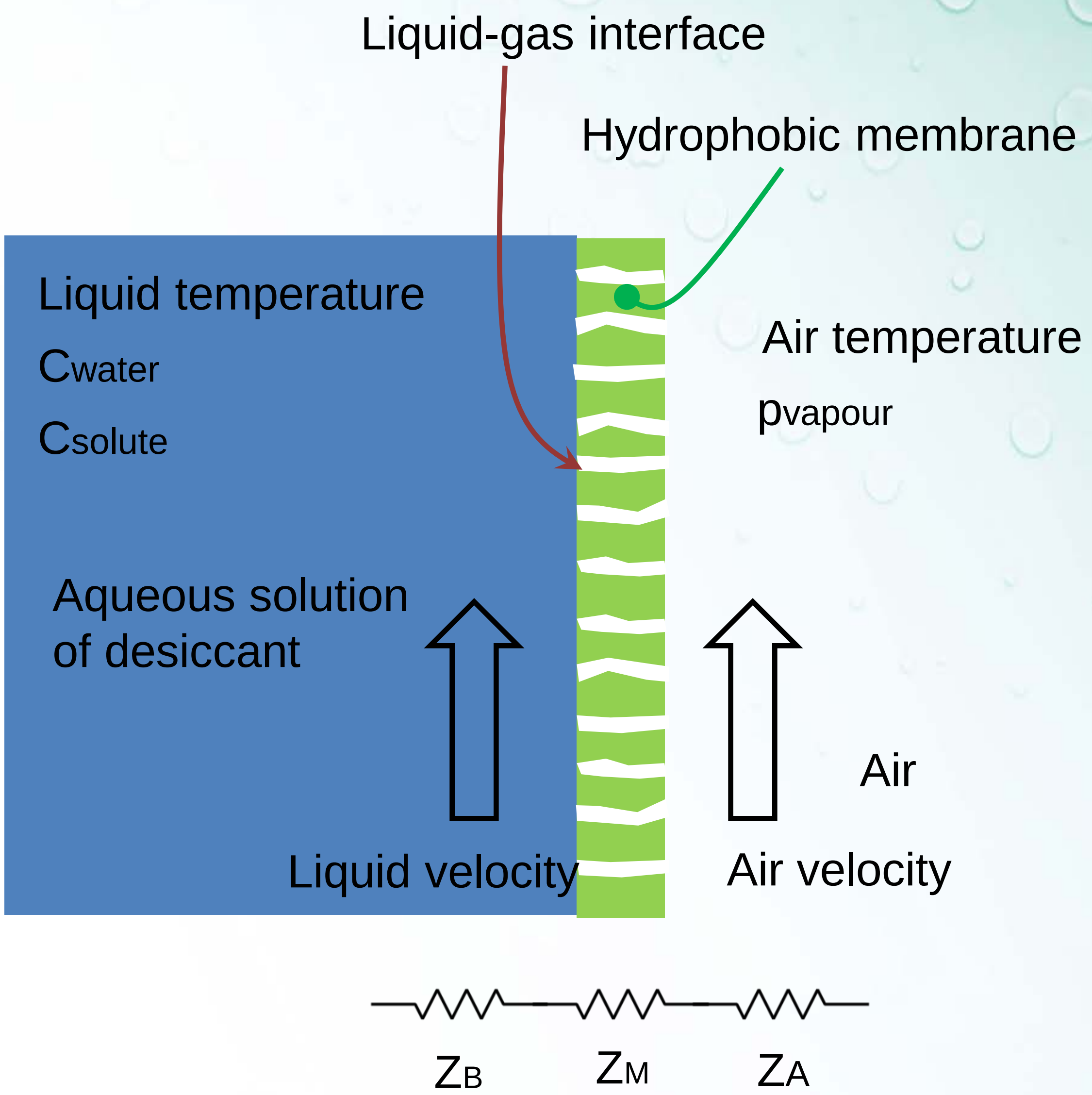
- Winter:

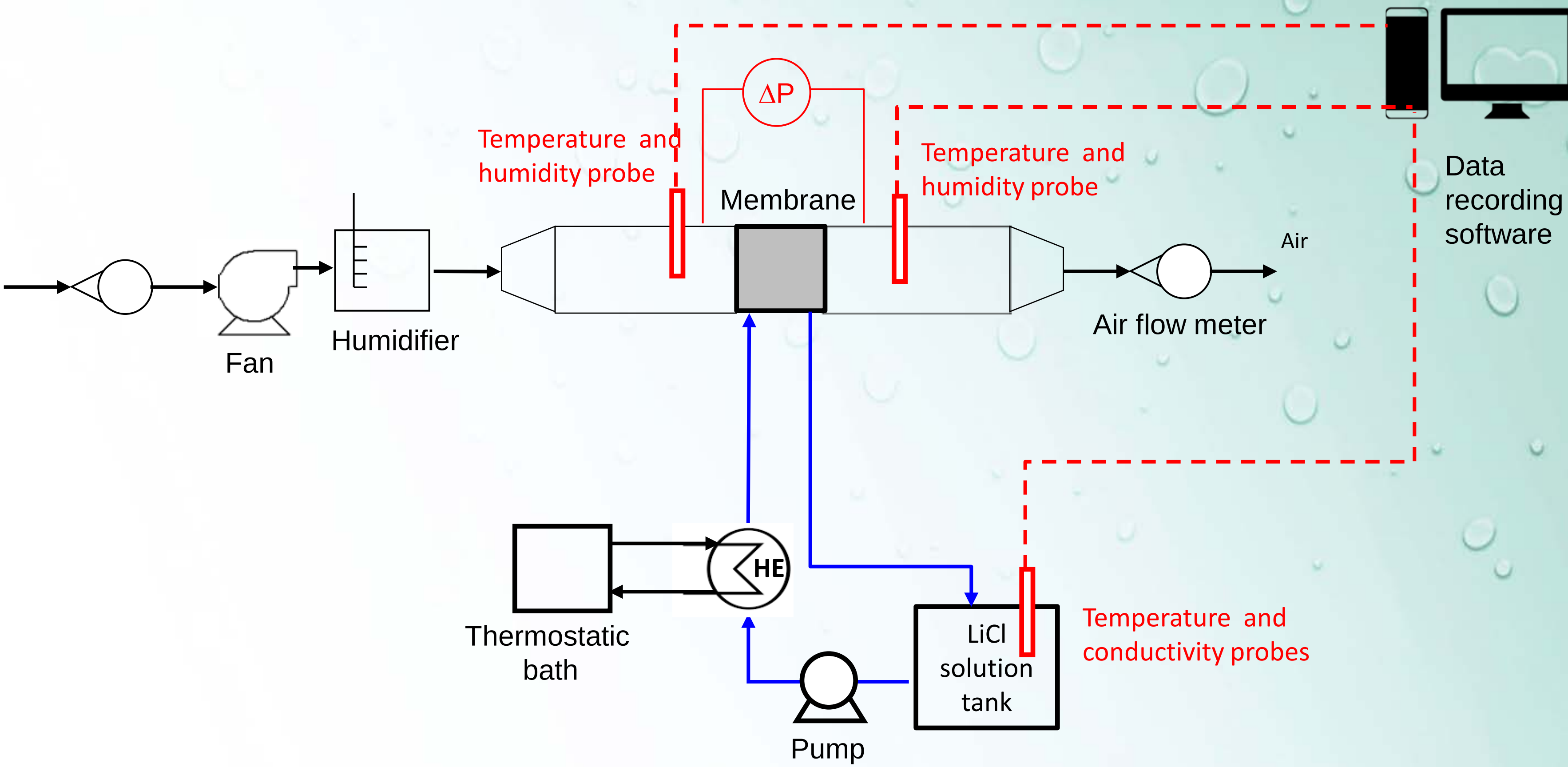
  XERIC system works as a heat pump, which is far more efficient than an electrical resistance.

Design of the 3F-CMC

- Theoretical studies and 3D CFD numerical simulations
- PVDF Membrane development
- Materials selection
- Manufacturing of the first prototype and tests in the lab
- Optimization

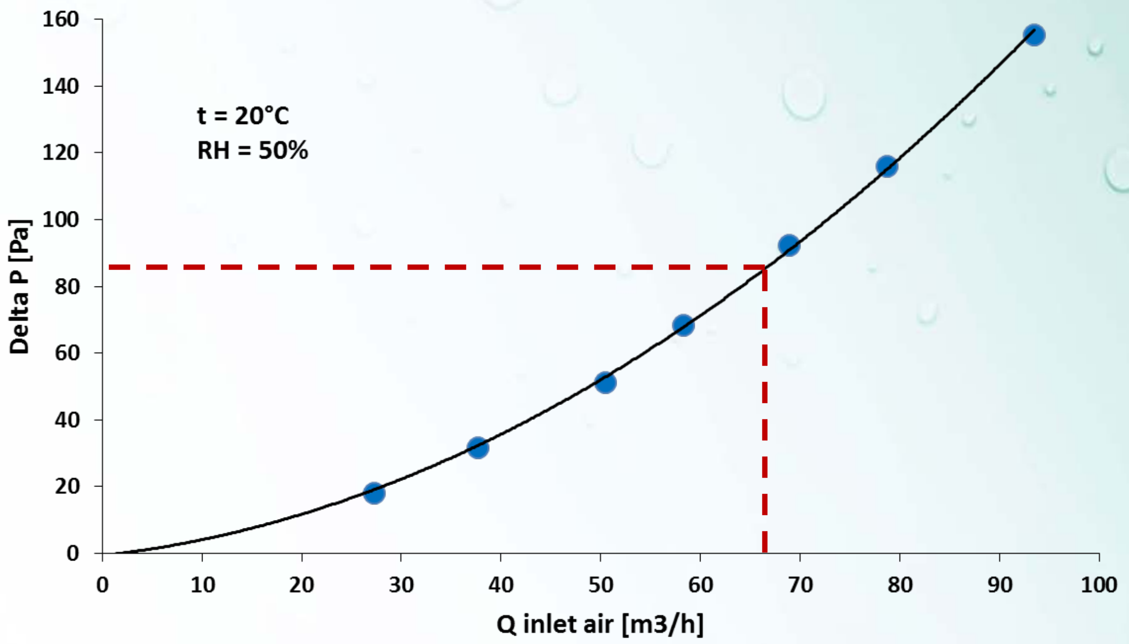
Characteristics
average pore size
pore size distribution
maximum thickness
surface tension
surface property
water vapour transmission resistance
stability in contact with desiccant
thermal resistance
chemical resistance


Liquid-gas interface
Hydrophobic membrane
Liquid temperature
C_{water}
C_{solute}
Aqueous solution of desiccant
Liquid velocity
Air temperature
p_{vapour}
Air
Air velocity
Z_B
Z_M
Z_A


ΔP
Temperature and humidity probe
Membrane
Temperature and humidity probe
Data recording software
Air
Fan
Humidifier
Air flow meter
HE
Thermostatic bath
LiCl solution tank
Temperature and conductivity probes
Pump

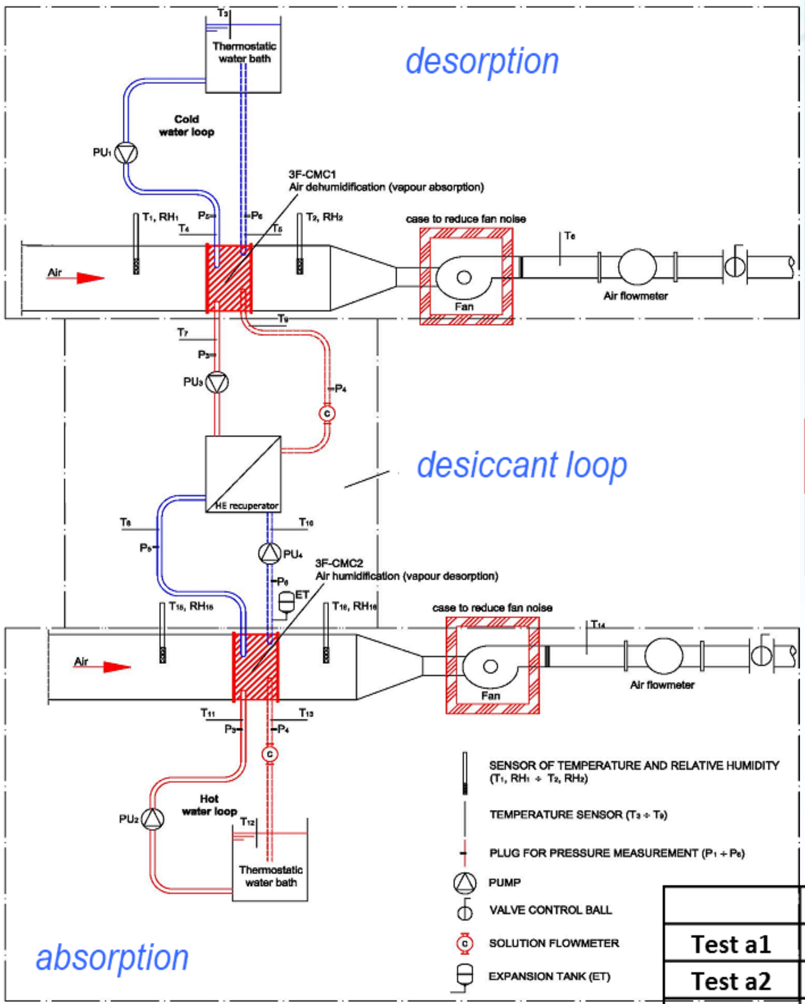
Air pressure drops through the 3F-CMC small-scale prototype

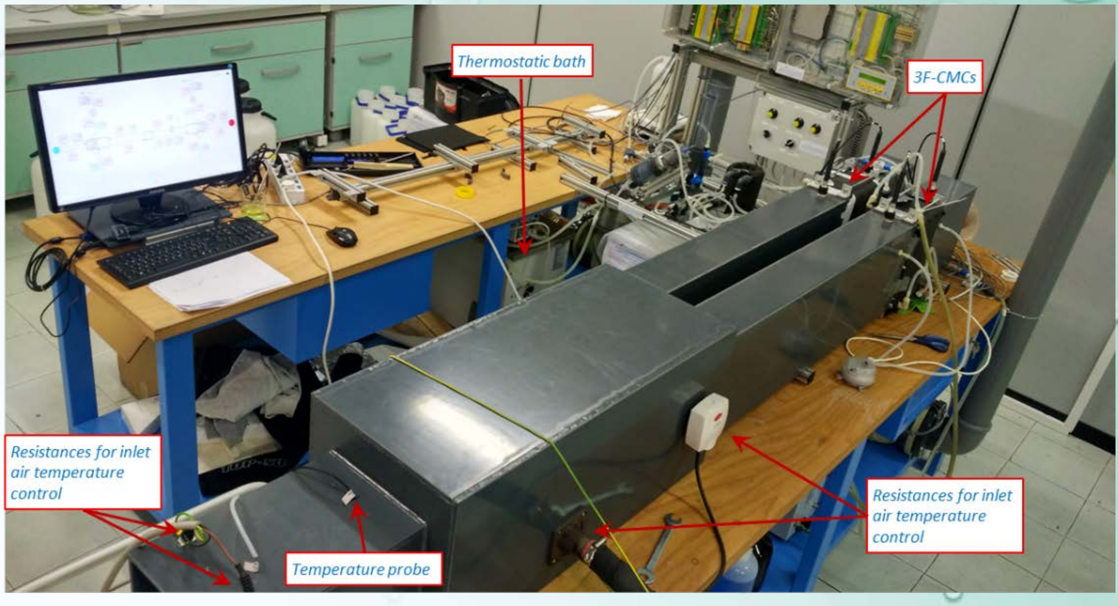
- The 3F-CMC design has been carried out by paying attention in not require high ventilation energy consumption.
- Tests have proven that an air pressure drop smaller than 100 Pa has been reached, as prescribed by the constraint of maintaining the current ventilators installed in Evs.



XERIC

LDC tests: water vapour absorption/desorption

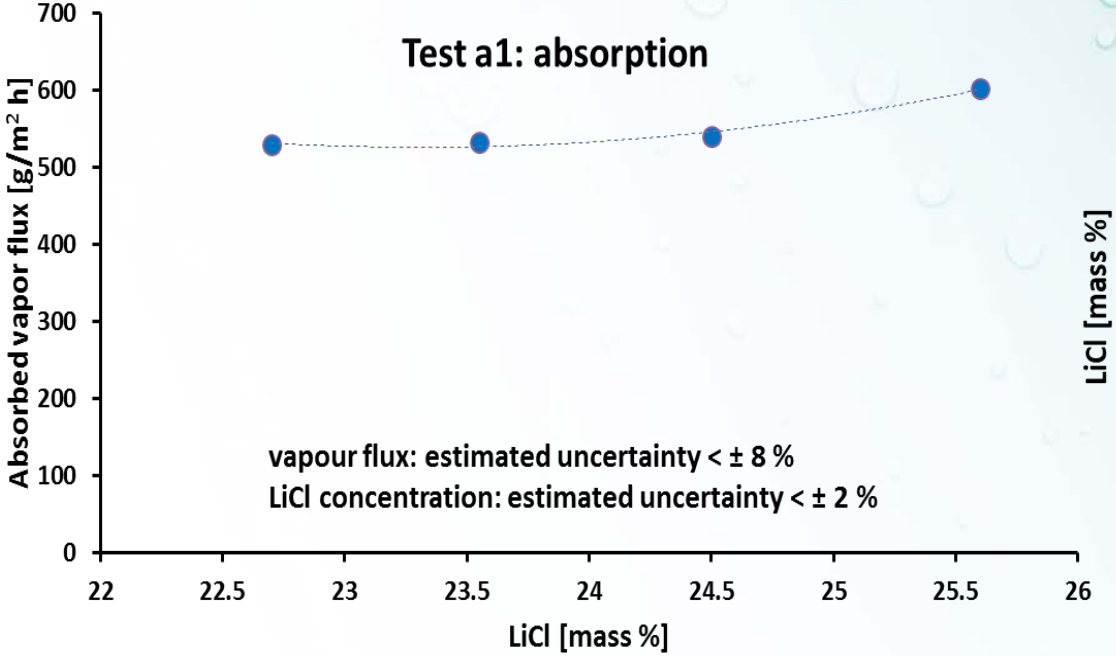


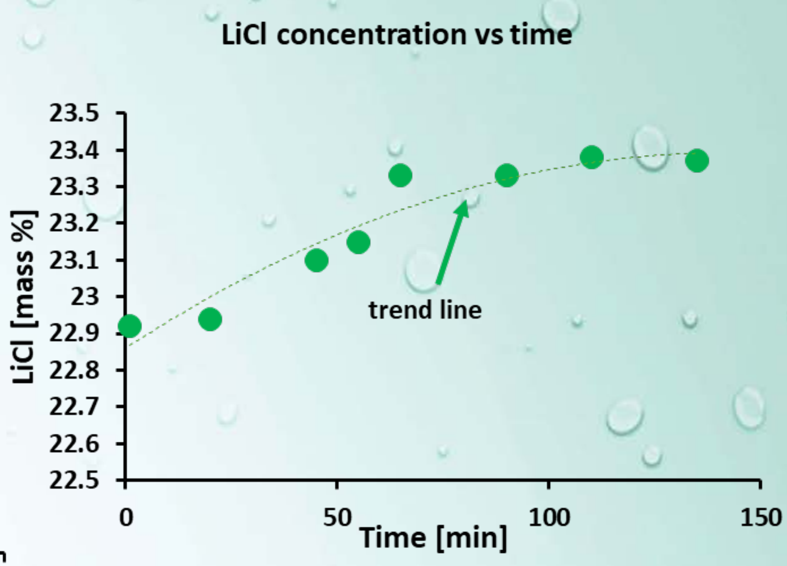


Experimental conditions:
Refrigerant → chilled water

	RH% in	T [°C] air in	x [g/kg a]	RH% out	T [°C] air out	Q air[m3/h]	T refr [°C]	Q LiCl [kg/h]
Test a1	63,0	30,5	**17,4**	89,7	19,3	66	15,1	20
Test a2	68,4	26,2	**14,6**	82,9	18,4	66	14,6	20
Test a3	61,0	22,0	**10,1**	74,3	16,2	66	11,6	20

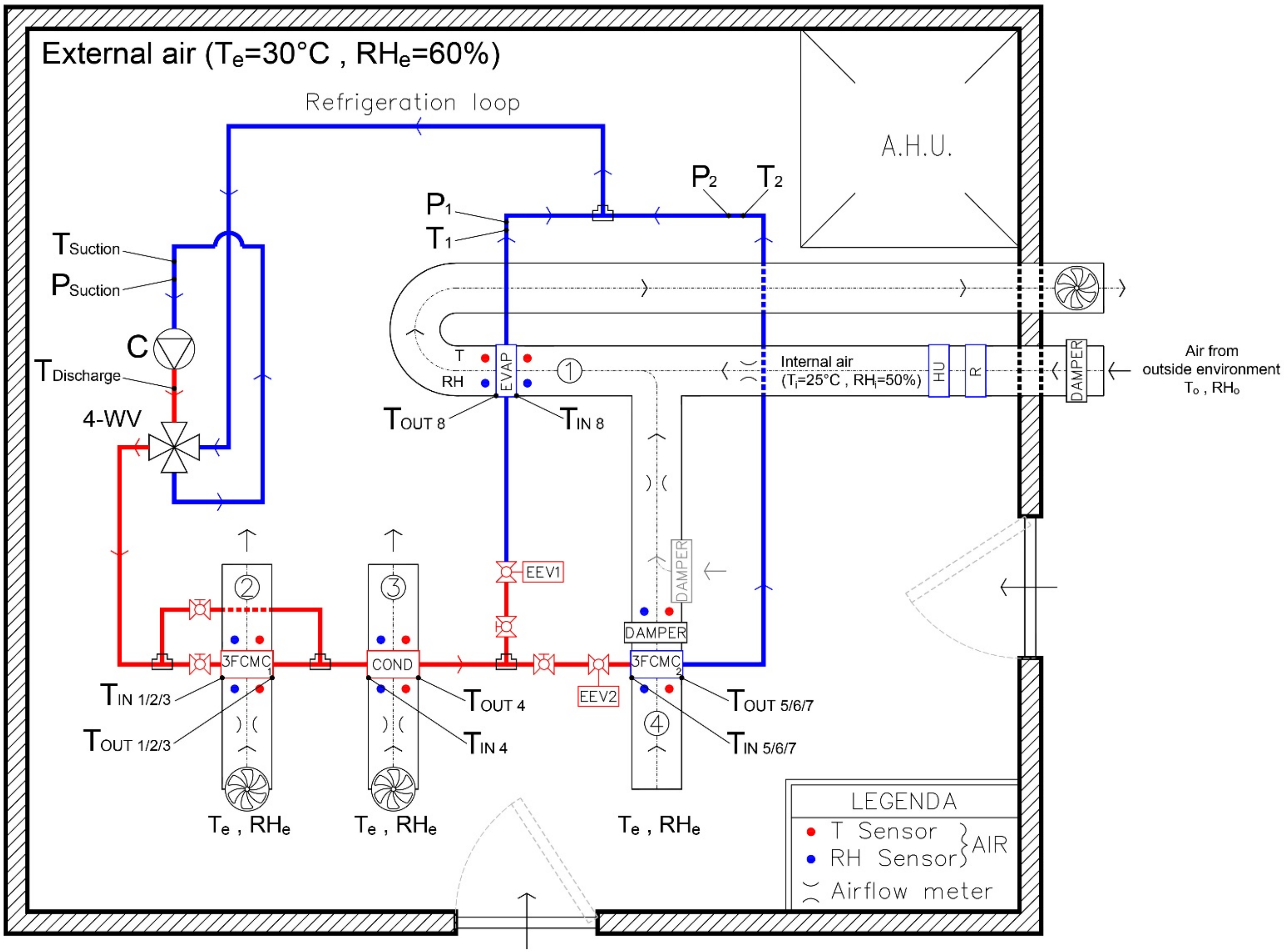
Some results about water vapour absorption





Lab tests on the XERIC AC SYSTEM

The Reference Climate-Control System (RCCS) employs a VCC to cool and to dehumidify the air in summer/intermediate seasons while in winter performs a direct electric heating.



Lab tests on the XERIC AC SYSTEM

The Reference Climate-Control System (RCCS) employs a VCC to cool and to dehumidify the air in summer/intermediate seasons while in winter performs a direct electric heating.

(1) compressor (rotary type, moved by a BLDC motor) and the inverter system controlling the BLDC motor (made of two main components, the power module and the control module)

(2) condenser (frontal area have been reduced to 1/3)

(3) Evaporator (frontal area have been reduced to 1/3)

(4)-(5) 3F-CMCs

(6) intermediate heat exchanger

(7) gear pump for the desiccant

Results:

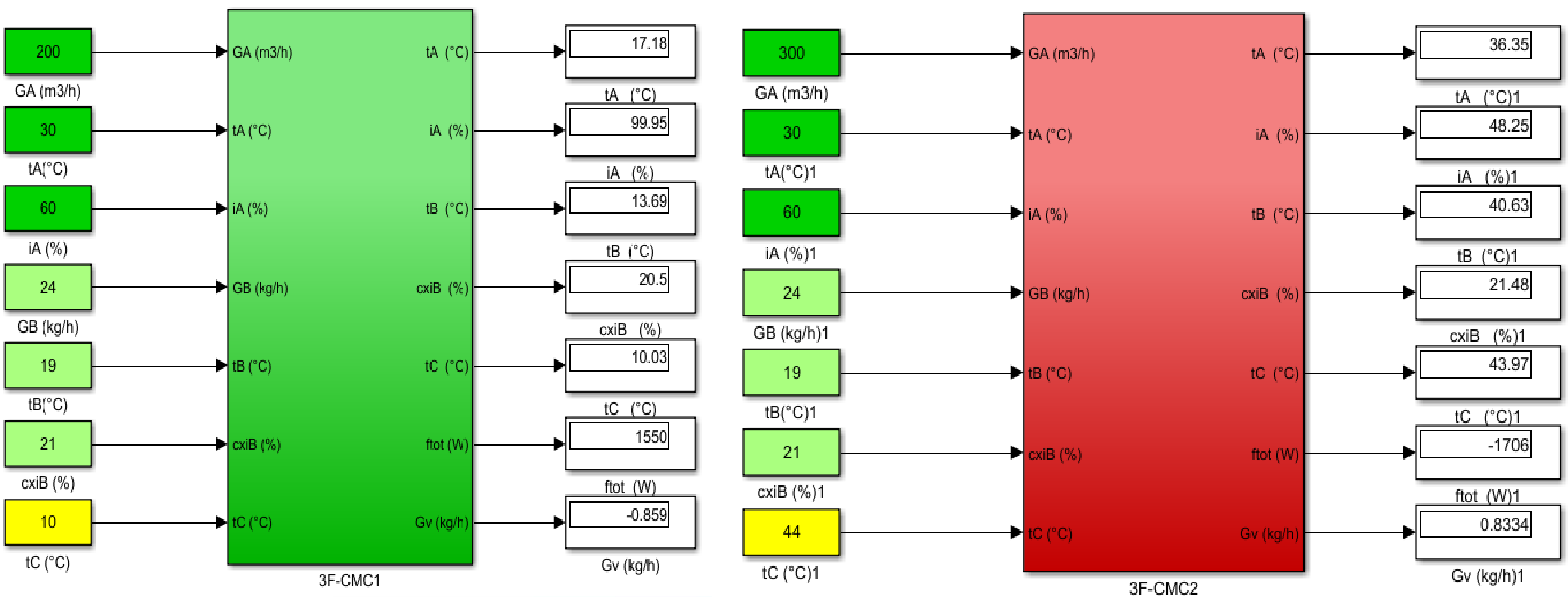
- desiccant circuit is stable (constant concentration and temperature of the desiccant)
- proper functioning of EEVs (the compressor inlet temperature remains constant)
- <u>**overall performance in good agreement with the theoretical predictions!!**</u>

Tests in the climatic chamber

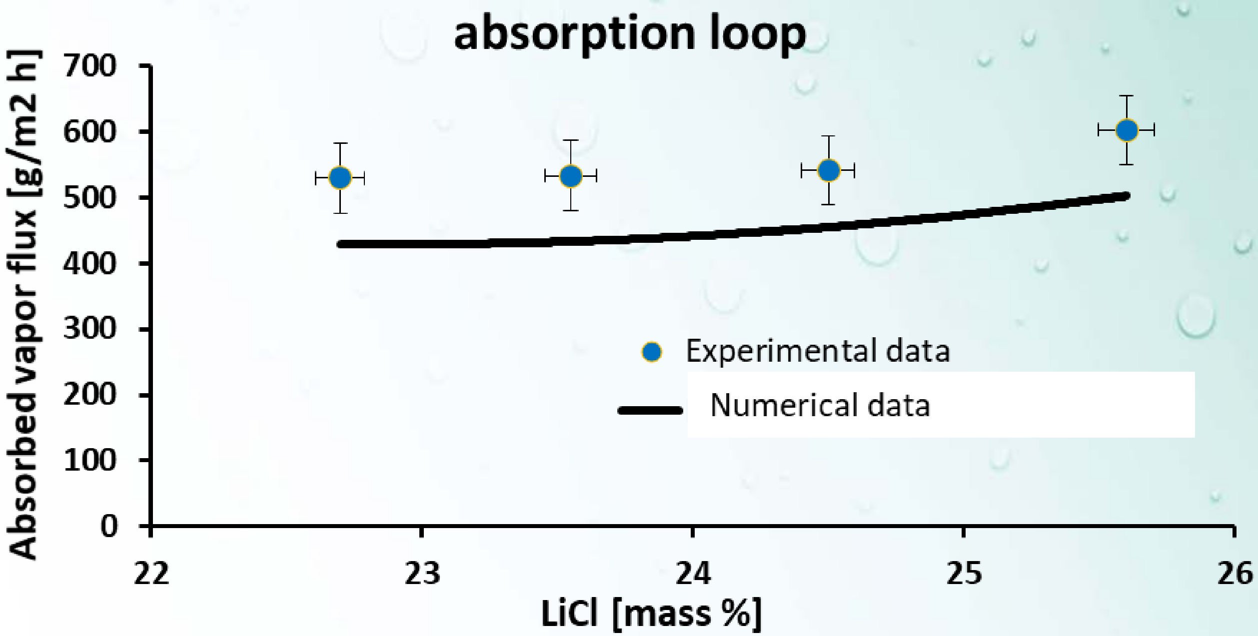
XERIC's system modeling activity

To model the XERIC AC system the Simulink blocks (MatLab©) of all its components (and 3F-CMC in particular) have been prepared, separately tested and debugged, and then connected.

Simplifying assumptions: steady-state regime; unidirectional and not compressible air flows; negligible heat transfer with the external environment; absence of uneven flow distributions within the components.

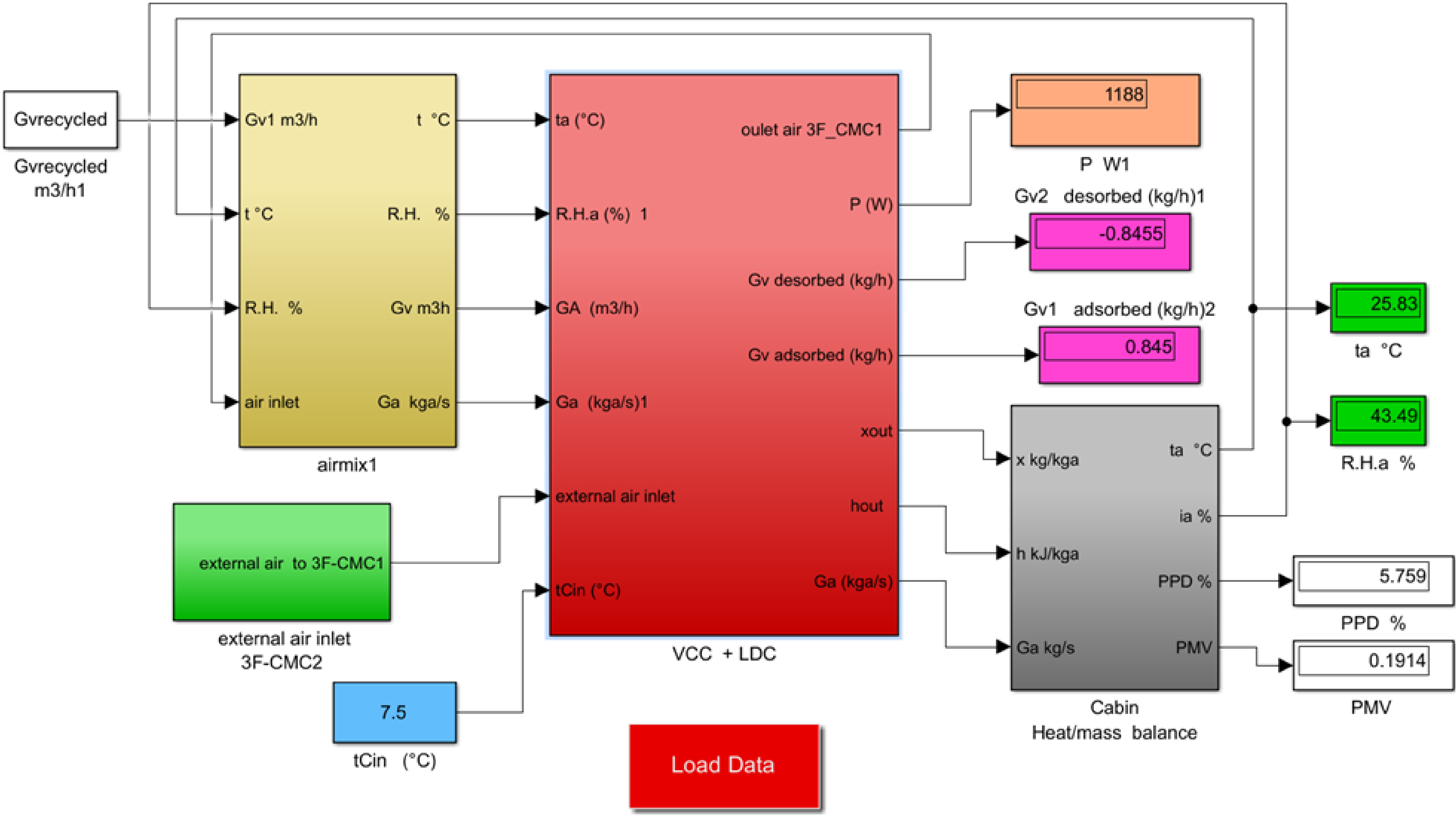


Experimental vs numerical results



The predicted trend is the same, whereas the predicted values are slightly underestimated, which is due to the values of the membrane properties adopted in the model (fine-tuning has been done).

Simulink scheme of the XERIC system



Conclusions

✓ A viable next generation of air conditioning system for EV has been designed, manufactured and proved good performance at lab level, which are aligned to those predicted:

1. reduce more than 50% the energy used all over the year for heating, cooling and dehumidifying air compared to existing systems;

2. reduce more than 30% the energy used for air cooling/dehumidifying in extreme summer conditions;

3. the performance of the XERIC prototype operating in the climate chamber set up at FRIGOMAR has been demonstrated at TRL6 (April 2018), close to market interest;

✓ Prototypes of 3F-CMC, designed, developed and manufactured (patents filed and/or under submission);

✓ Extensive know-how reached in:

- developing customized membranes with pre-specified characteristics;
- thermodynamics analysis of advanced air-conditioning systems and their components;
- high level laboratory facilities for testing air-conditioning devices and components;
- modeling and simulation of air-conditioning and related systems and processes.

THANK YOU FOR YOUR KIND ATTENTION