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# DEVELOPMENT AND CHARACTERIZATION OF A CALIBRATED CALORIMETER TO EVALUATE AIR CONDITIONING SYSTEMS

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**Abstract.** *The objective of this work is to design and characterize a calibrated calorimeter for validating the performance of air conditioning (AC) systems and to compare their results with those obtained from tests performed with a certificated calorimeter. The main goal of the apparatus is not to certify AC, but rather to provide reliable performance data for these systems, in particular a magnetic refrigeration system under development at POLO Laboratories. Given the goal of the apparatus, the design is based on the standard's requirements, although some adaptations were made due to budget, equipment and physical space restrictions. Among the main adaptations, the humidity control is present only at the cold side (CS) chamber and, for the purpose of supporting and better accommodating the magnetic cooling prototype, the base of the hot side (HS) chamber is in direct contact with the room floor. Furthermore, temperature controls are measured by 9 thermocouples at the CS, 9 at the HS and 7 outside the calorimeter. Temperature control in the CS is performed through electrical heaters, in the HS by a chiller coupled to fan-coil and in the room by ambient air-conditioners. An average global heat transfer coefficient, for the conditions under which the AC will be tested, was obtained for the walls in contact with the room, which for the CS is 0.568 W/(m<sup>2</sup>K) and for the HS is 0.843 W/(m<sup>2</sup>K). Lastly, for the purpose of evaluating the impact of such adaptations in the obtained results, a reference air-conditioner, which was previously evaluated with a certified calorimeter, was tested with the apparatus. The results were compared and used to calibrate the developed calorimeter in order to perform future tests with the apparatus.*

**Keywords:** *Thermodynamic characterization, calorimeter, calorimeter method, performance comparison, cooling capacity, vapor compression systems.*

## 1. INTRODUCTION

Validation and characterization of air conditioning (AC) systems are usually an expensive and onerous stage in the development of these equipment. Among several options established by the ruling standards, calorimeter methods are widely used both in academic and industrial environments. In general, a calorimeter used to evaluate the performance

of an AC is a chamber divided into two independent environments, one for the AC evaporator unit and other for the condenser unit, both with temperature and humidity control (Ribeiro, 2015).

An adapted calorimeter was designed and built at Polo Laboratories, in order to evaluate a 9000 BTU/h magnetic air conditioning device and other future prototypes from the laboratory. The design, characterization and validation of the apparatus are covered in this work. This project is based, mostly, on the ABNT/NBR-15372 (2006), ANSI/ASHRAE 16-1983 (2009) and ISO-5151 (2017), but it does not follow all demands established by those standards.

Starting with the apparatus structural design, according to ISO-5151 (2017) and ANSI/ASHRAE 16-1983 (2009), the size of the calorimeter should be sufficiently large to avoid any flow restriction in the intake and discharge of the AC as well as to provide a distance of at least 1 m from the air conditioning equipment and the walls of the chamber. All walls of the calorimeter must be at a distance of at least 460 mm from the surfaces around it (ABNT/NBR-15372, 2006). The interior of the calorimeter also must contain an insulated partition between the condenser and the evaporator chambers, by which a pressure-equalizing device and the AC should be installed (ISO-5151, 2017; ANSI/ASHRAE 16-1983, 2009).

Besides that, reconditioning equipment is necessary to maintain specified airflow as well as to control humidity and temperature of both chambers (ISO-5151, 2017; ANSI/ASHRAE 16-1983, 2009). Also, measurements of wet and dry-bulb temperature, water and energy supply are necessary and must follow the uncertainties tolerances presented at Tab. 1.

Table 1: Measurement uncertainties according to Standards

Measurement	ABNT/NBR-15372 (2006)	ANSI/ASHRAE 16-1983 (2009)	ISO-5151 (2017)
Water temperature	$\pm 0.3$ °C	$\pm 0.3$ °C	$\pm 0.1$ °C
Air dry-bulb temperature	$\pm 0.1$ °C	$\pm 0.05$ °C	$\pm 0.2$ °C
Air wet-bulb temperature	$\pm 0.1$ °C	$\pm 0.05$ °C	$\pm 0.2$ °C
Relative Humidity	$\pm 2$ %	-	-
Electrical measurements	$\pm 1$ % (heaters, humidifiers) $\pm 2$ % (motors, fans, pumps)	$\pm 0.5$ %	$\pm 0.5$ %
Atmospheric Pressure	$\pm 1$ % or 0.5 Pa	$\pm 1.25$ Pa	$\pm 5$ %
Mass	$\pm 0.5$ %	$\pm 1$ %	$\pm 1$ %

In order to comply with the requirements established for the project, especially those related to budget, physical space and equipment availability, the calorimeter designed at Polo is an adaptation of the recommendations present in the standards cited above. Among the most significant changes, there is the absence of a pressure-equalizing device between chambers, the lack of a humidity control system in the hot side chamber, the design of the chambers with smaller dimensions than the ones recommended, the use of measurement equipment which does not comply with tolerances established by standards, the indirect measurement of wet bulb temperature and the distance between the base of the condenser side and the room floor.

Throughout this work, the impacts of those adaptations are analyzed, in order to obtain reliable results from the tests executed with the calorimeter. The characterization of heat transferred through the walls of the device is presented as well as the results of capacity tests performed by an inverter AC, also tested at a certificated calorimeter.

## 2. EXPERIMENTAL APPARATUS

Based on the standard recommendation and available physical space, the device developed at Polo is 2.2 m wide, 4.86 m long and 2.64 m high. The 10.7 m<sup>2</sup> calorimeter, pictured in Fig. 1, is divided into two chambers thermally isolated from each other: the cold side (CS), for the evaporator unity of the AC, and the hot side (HS), for the condenser unity. The area surrounding the calorimeter is called outside (OS) and it refers to the room where it is situated. The walls of the apparatus are made with Polyisocyanurate, in order to enhance thermal insulation. Different from the recommendation found in the standards, this calorimeter is closer than 460 mm from the ground and the ceiling of the room, due to physical space restrictions. Also, the base of the HS is in direct contact with the floor, in order to better accommodate the magnetic air conditioning device. There is no pressure-equalizing device between CS and HS, instead of that, 3 pressure transducers are used to measure the pressure inside each environment.

To better choose the reconditioning equipment, it is important to estimate the amount of heat transferred through the walls of the calorimeter at specific tests conditions. In order of this, an theoretical overall heat transfer coefficient ( $U_{theoretical}$ ) was defined at the beginning of the calorimeter design. The thermal conductivity of the Polyisocyanurate from the walls at 23.8°C is approximately 0.027 W/(mK) (Bernardi, 2017) and the convection coefficient ( $h_{air}$ ) is estimated to be 8 W/(m<sup>2</sup>K) for the condition of heat transfer over flat plates disregarding the effects of the orientation of the walls.

In order to calculate the overall heat transfer coefficient, it is considered a condition in which the heat transfer is one-dimensional as well as inside the walls the heat is transferred by conduction and between the walls and surroundings is transferred only by convection. Considering the analogy between thermal and electric resistances (Incropera *et al.*, 2007),



(a) Cold Side Chamber.

(b) Hot Side Chamber.

(c) External view of the calorimeter.

Figure 1: Pictures of inside and outside the calorimeter from Polo Laboratories

the heat transfer coefficient for the walls of the calorimeter can be estimated by the Eq. (1) and (2), wherein the variable  $R_{total}$  corresponds to the total thermal resistance,  $A$  is the area of the walls under the action of convection effects and  $L$  is the thickness of the analyzed walls. The results for each chamber and for the partition wall are presented at Tab. 2.

$$R_{total} = \frac{1}{A * U_{theoretical}} = \frac{1}{A * h_{air}} + \frac{L}{A * k_{walls}} + \frac{1}{A * h_{air}} \quad (1)$$

$$U_{theoretical} = \frac{1}{\left(\frac{1}{h_{air}} + \frac{L}{k_{walls}} + \frac{1}{h_{air}}\right)} \quad (2)$$

Table 2: Results of theoretical overall heat transfer coefficient

Wall analyzed	Overall heat transfer coefficient
Partition wall	0.148 [W/(m <sup>2</sup> K)]
CS outer walls	0.304 [W/(m <sup>2</sup> K)]
HS outer walls	0.304 [W/(m <sup>2</sup> K)]

The CS is equipped with the evaporator unit, a set of 4 pairs of air resistances, with a total supply capacity of 3500 W, combined with 4 fans, providing proper airflow to the chamber. Also, there are 2 reservoirs, each with 2 water resistances, for the purpose of controlling the relative humidity inside the chamber. The CS acquisition system is composed of 9 thermocouples measuring ambient temperature, 1 thermocouple in the discharge of the evaporator, 1 thermocouple measuring water reservoir temperature, 8 relative humidity transducers and a pressure transducer. Also, there is a balance measuring the mass of water condensed at the heat exchangers of the evaporator unit. The power of the set of fans, of each water resistance and of air resistances pairs are measured by power transducers with a range of 1000 W.

The HS is composed of the condenser unit, a fan-coil coupled to a chiller, providing temperature control to the chamber, and one fan to increase airflow. There is no humidity control inside the HS, hence this parameter is only monitored there. Ambient conditions measurements are done by 9 thermocouples, 8 relative humidity transducers and a pressure transducer. The power supply for the fan-coil and the air conditioning device are measured by a 1000 W and a 2000 W power transducer, respectively.

Lastly, the temperature of the OS is controlled by ambient air-conditioners and measured by 7 thermocouples. Also at the OS, there is a pressure transducer and a thermo hygrometer, which provides temperature and humidity measurements. The list of reconditioning equipment used in the three ambients as well as their specifications can be found in Tab. 3 while a list of measurement equipment and their uncertainties can be found in Tab. 4.

According to Tab. 1 and Tab. 4, the air temperature, relative humidity and pressure measurements of the calorimeter from Polo do not comply with the standards recommendations. Also, the uncertainty of water temperature measurement is above the uncertainty tolerated by ISO-5151 (2017). For power measurements of AC consumption, fans as well as air and water resistances below 720 W, the uncertainty is higher than the  $\pm 0.5\%$  recommended by ANSI/ASHRAE 16-1983 (2009); ISO-5151 (2017). Besides that, as the maximum consumption of the fan-coil is 248 W, the measurement error of its power is always out of recommended ranges from the three standards cited.

Table 3: Reconditioning equipment used in the calorimeter and their specifications

Reconditioning equipment used	Quantity	Specifications
Air resistances	8	4 sets with 2 resistances in series, power of 1750W/220V each
Water resistances	4	Immersion resistances, power of 1000W/220V
Water reservoirs	2	Stainless steel tanks, capacity of 30 liters each
Fans	5	Axial fan, 200 W power input, maximum airflow 3540 m <sup>3</sup> /h
Fan-coil	1	30000 Btu/h capacity, airflow of 1291 m <sup>3</sup> /h, 248 W power input
Chiller	1	Maximum capacity of 9000 kcal/h, work temperature from -10°C to 25°C

Table 4: Measurement uncertainties of equipment used in the calorimeter

Measurement equipment	Uncertainties of the calorimeter
Thermocouples	± 0.25°C
Relative Humidity Transducers	± 2.8 %
Thermo hygrometer (temperature measurement)	± 0.12 °C
Thermo hygrometer (relative humidity measurement)	± 2 %
Power Transducers (1000 W range)	± 3.6 W
Power Transducers (2000 W range)	± 3.6 W
Pressure Transducers	± 2 kPa
Balance	± 0.1 g

### 3. EXPERIMENTAL METHOD

The characterization of the apparatus is done in two stages. The first one is the calibration, by which the experimental overall heat transfer coefficient ( $U_{real}$ ) for the walls of the calorimeter is determined, based on their theoretical area. The second one is the capacity test of a conventional vapor compression AC, with inverter technology, which was tested at a certified calorimeter beforehand.

Starting with the calibration stage, by performing it, the main goal is to define the ratio between the heat transfer rate and temperature difference imposed (UA) for the outside and partition walls of the calorimeter. In order to determine that, a temperature difference is imposed between each of the three environments and surroundings and then the heat supply to the analyzed chamber is measured, according to procedures proposed by the standards (ABNT/NBR-15372, 2006; ANSI/ASHRAE 16-1983, 2009; ISO-5151, 2017). At first step, the CS is heated by the air resistances and the HS and OS are kept at a constant temperature, lower than the CS temperature, after this, the same procedure is done at the HS. Lastly, both HS and CS are heated to the same temperature, while the OS is kept at a lower constant temperature. According to ABNT/NBR-15372 (2006), ANSI/ASHRAE 16-1983 (2009) and ISO-5151 (2017), the temperature difference must be at least 11°C between the chamber analyzed and the surroundings. Once the steady state is established at the system, it is possible to measure how much power is needed to keep that temperature difference.

At a steady state condition, an energy balance can be applied in the control-volume around the chamber of interest. Equations (3) to (5) represent the energy balance from tests performed in the CS, in the HS and in the whole calorimeter. For those equations, the  $\dot{Q}_{CS}$ ,  $\dot{Q}_{HS}$  and  $\dot{Q}_{CS,HS}$  are the steady state heat flow measured when analysing the CS, the HS and the two chambers, respectively. Also,  $\dot{Q}_{OuterWalls)CS}$  and  $\dot{Q}_{OuterWalls)HS}$  are the heat transferred through the walls of each chamber, except through the partition one. Finally,  $\dot{Q}_{PartitionWall}$  is the amount of heat flow at the division wall of the chamber.

$$\dot{Q}_{CS} = (\dot{Q}_{OuterWalls)CS} + \dot{Q}_{PartitionWall} \quad (3)$$

$$\dot{Q}_{HS} = (\dot{Q}_{OuterWalls)HS} + \dot{Q}_{PartitionWall} \quad (4)$$

$$\dot{Q}_{CS,HS} = (\dot{Q}_{OuterWalls)CS} + (\dot{Q}_{OuterWalls)HS} \quad (5)$$

Since areas of the division wall and outside walls in each chamber are known, it is possible to calculate an average U for CS outside walls, one for HS outside walls and other for the partition, as presented in equations (6) to (10). Therefore, for other tests executed with the calorimeter, the amount of heat transferred to a chamber can be calculated based on the temperature difference between the environments.

$$\dot{Q} = U * A * \Delta T \quad (6)$$

Wherein the relation  $U * A$  is a constant value for same convection conditions.

$$(UA)_{CS,HS} = [(UA)_{CS} - (UA)_{PartitionWall}] + [(UA)_{HS} - (UA)_{PartitionWall}] \quad (7)$$

$$(UA)_{PartitionWall} = \frac{(UA)_{CS} + (UA)_{HS} + (UA)_{CS,HS}}{2} \quad (8)$$

$$[(UA)_{OuterWalls}]_{CS} = (UA)_{CS} - (UA)_{PartitionWall} \quad (9)$$

$$[(UA)_{OuterWalls}]_{HS} = (UA)_{HS} - (UA)_{PartitionWall} \quad (10)$$

The cooling capacity test is done repeating the test conditions which the AC was tested in advance, at a laboratory with a certified calorimeter. Temperature and humidity conditions are presented at Tab. 5. In both tests, the AC works at maximum capacity mode. In this experiment, once the steady state is achieved, measurements of temperature, humidity, power consumption, mass and pressure are saved for at least 30 minutes.

Table 5: Ambient conditions of capacity tests performed at certified lab

Environment of the apparatus	Dry-bulb temperature	Wet-bulb temperature	Relative Humidity
Cold Side (Test 1)	17°C	11.4°C	-
Cold Side (Test 2)	22°C	15.5°C	-
Cold Side (Test 3)	26.7°C	19.4°C	-
Hot Side	35°C	23.9°C	-
Outside Calorimeter	23°C ± 5°C	-	55% ± 15%

To calculate the cooling capacity ( $Q_{cooling}$ ) of the equipment is necessary to apply the principles of the first law of thermodynamics (Eq. 11) at the control-volume represented at Fig. 2.

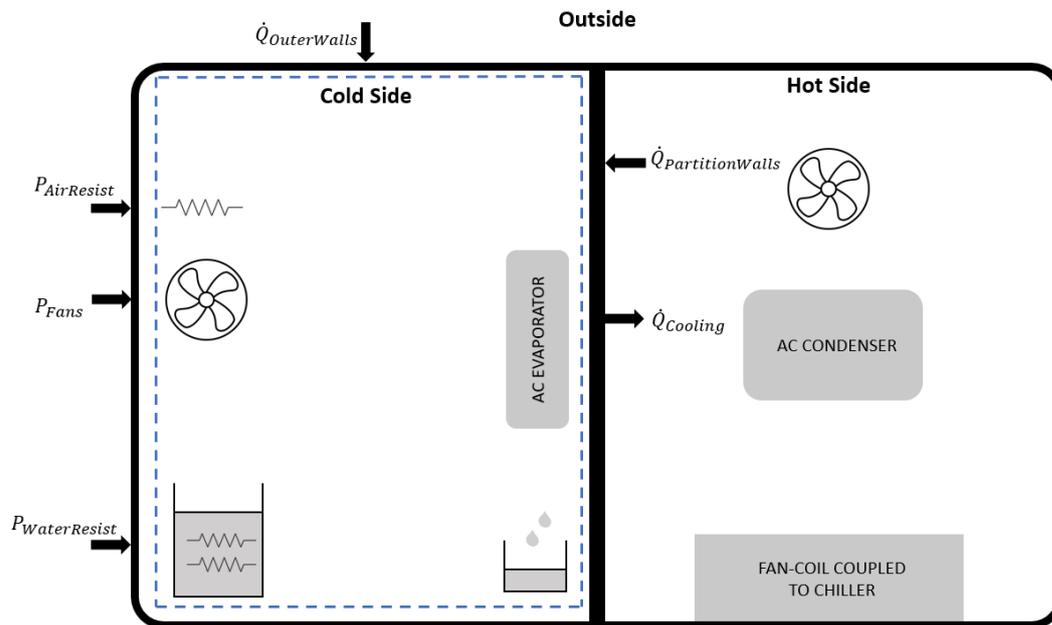


Figure 2: Representation of the energy balance in the CS.

$$(\dot{Q}_{in} - \dot{Q}_{out}) + (\dot{W}_{in} - \dot{W}_{out}) + [(\dot{E}_{mass})_{in} - (\dot{E}_{mass})_{out}] = \frac{dE_{system}}{dt} \quad (11)$$

Wherein the term  $(\dot{Q}_{in} - \dot{Q}_{out})$  represents the heat variation in the control volume,  $(\dot{W}_{in} - \dot{W}_{out})$  is the power variation and  $[(\dot{E}_{mass})_{in} - (\dot{E}_{mass})_{out}]$  is the energy variation related to mass flow through the control volume. Finally, the term  $dE_{system}/dt$  is the ratio between energy variation of the system throughout the test and the duration of the procedure. Since there is not any mass flow through the boundary of the control volume, considering all heat and power inputs and outputs, the Eq 11 can be rewritten as presented at Eq. 12 to 15.

$$(\dot{Q}_{in} - \dot{Q}_{out}) + (\dot{W}_{in} - \dot{W}_{out}) = \frac{\Delta E_{system}}{\Delta t} \quad (12)$$

$$(\dot{Q}_{in} - \dot{Q}_{out}) + (\dot{W}_{in} - \dot{W}_{out}) = P_{Fans} + P_{AirResist} + P_{WaterResist} + \dot{Q}_{Walls} - \dot{Q}_{Cooling} \quad (13)$$

$$\Delta E_{system} = (P_{Fans} + P_{AirResist} + P_{WaterResist} + \dot{Q}_{Walls} - \dot{Q}_{Cooling}) * \Delta t \quad (14)$$

$$\Delta E_{system} = (E_{final} - E_{initial})_{system} \quad (15)$$

In the equations above, the  $\dot{Q}_{cooling}$  is the cooling capacity calculated, while the  $P_{Fans}$ ,  $P_{AirResist}$ ,  $P_{WaterResist}$  are the electrical power measured of fans, air resistances and water resistances, respectively. The heat flow through partition and CS external walls is named as  $\dot{Q}_{Walls}$ . Also, to calculate the energy variation of the system throughout the test, a mass balance (Eq. 16 and 17) is applied for the control-volume at the beginning and ending of the procedure, as depicted in Fig 3.

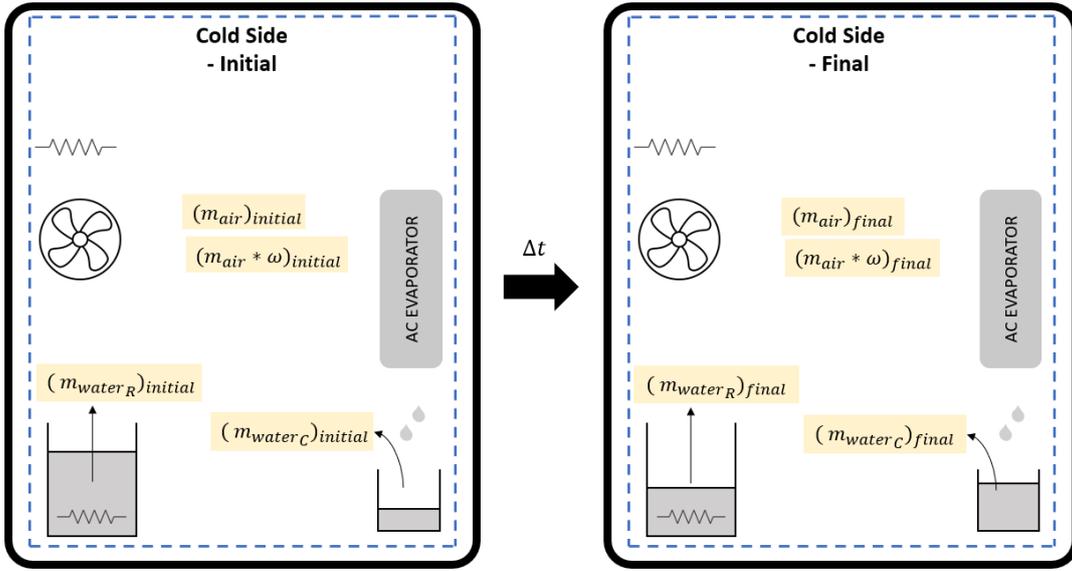


Figure 3: Representation of mass balance inside the calorimeter, for the initial and final states of the test.

$$(m_{air})_{initial} = (m_{air})_{final} \quad (16)$$

$$(m_{water_R} + m_{water_C} + m_{air} * \omega)_{initial} = (m_{water_R} + m_{water_C} + m_{air} * \omega)_{final} \quad (17)$$

The  $m_{air}$  terms refer to the mass of air present inside the CS at the beginning and end of the test. The  $m_{water_R}$  and  $m_{water_C}$  are the mass of water in the evaporation reservoir and in the condensate deposit, respectively. Lastly, the  $\omega$  is the specific humidity inside the chamber.

Considering that relative humidity inside the CS is kept constant throughout the test and that ambient pressure does not vary, the Eq. 16 and 17 can be simplified to Eq. 18.

$$-\Delta m_{water_R} = -\Delta m_{water_C} \quad (18)$$

Since the inside temperature is also kept constant along the test, the energy variation of the system is now written as in Eq. 19.

$$\Delta E_{system} = [(m_{water} * h_{water})_R + (m_{water} * h_{water})_C]_{final} - [(m_{water} * h_{water})_R + (m_{water} * h_{water})_C]_{initial} \quad (19)$$

In the equation above, the  $h_{water}$  is the enthalpy of the water, in liquid state, inside each reservoir. Assuming that both temperature of the water are constant along the test, the enthalpy can be determined as also constant and the Eq. 19 becomes:

$$\Delta E_{system} = \Delta m_{water} * (h_{water_C} - h_{water_R}) \quad (20)$$

Finally, from Eq. 14 and Eq. 20, the cooling capacity can be determined as in Eq. 21.

$$\dot{Q}_{Cooling} = P_{Fans} + P_{AirResist} + P_{WaterResist} + \dot{Q}_{Walls} + \frac{\Delta m_{water}}{\Delta t} * (h_{water_C} - h_{water_R}) \quad (21)$$

## 4. RESULTS AND DISCUSSIONS

In this section, the results of the calibration and capacity tests are presented, as well as a comparison with the results obtained at the certified calorimeter. The main objective of performing the calibration is to determine the experimental UA of walls from the calorimeter and then have more reliable values of heat transfer rate to the neighborhood, according to the temperature of the three environments. After determining the experimental UA, the capacity test of a vapor compression AC is executed at the calorimeter in order to analyze its cooling capacity, consumption and COP. In a second moment, the results obtained at the calorimeter are discussed and compared with the ones obtained at a certified lab.

### 4.1 Calibration

The calibration of the calorimeter was executed at three stages. At the first one, the CS was heated until an average temperature of 65°C. Even though the standards establish a temperature difference of 11°C between the inlet and outlet chambers, the temperature of this test was determined based on the minimum temperature achieved by the chamber in steady state when only the fans were turned on. Once the ratio  $\dot{Q}/\Delta T$  should be constant regardless of the operation temperature, other two tests were executed at the CS, one at 67°C and other at 70°C. The HS and the OS were maintained at  $25.5 \pm 0.5$  °C during the three tests. The results of  $\dot{Q}/\Delta T$  in steady state conditions (UA) for the tests performed at the CS are presented at fig 4.

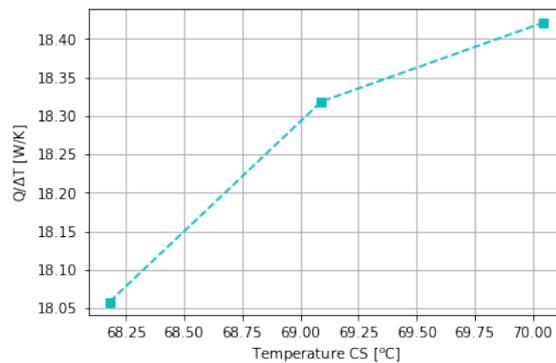


Figure 4: Results of calibration tests performed at the CS chamber.

The second stage of the calibration tests was to evaluate the HS chamber. The same procedure carried out at the CS was replicated at the HS. In order to enable the temperature increase and control at the HS, two pairs of air resistances, the same ones used in the CS, were installed as well as two power transducers. Three tests were performed at an average temperature of 65°C, 67°C and 70°C. The temperature in the CS and at the OS was  $24.2 \pm 0.5$  °C. These results are depicted in Fig 5.

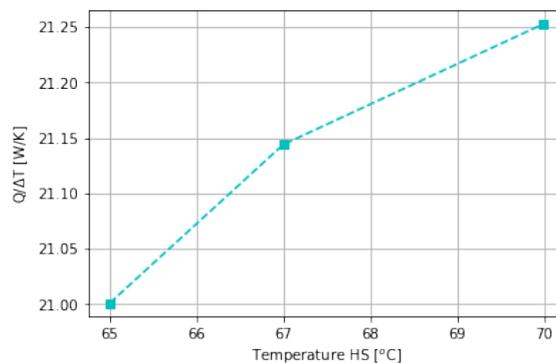


Figure 5: Results of calibration tests performed at the HS chamber.

Finally, three tests evaluating both chambers at the same time were performed. Once the two chambers were kept at the same temperature and there was no heat exchange through the partition wall, the minimum temperature to achieve steady state increased. In result of this, the two chamber tests were executed keeping an inside average temperature of 66°C, 68°C and 70°C, as depicted at Fig. 6.

At Tab. 6, the experimental  $\dot{Q}/\Delta T$  and U calculated for each group of walls (CS outer walls, HS outer walls and partition wall) are presented. To calculate them, it was considered the average UA and the theoretical area of each chamber.

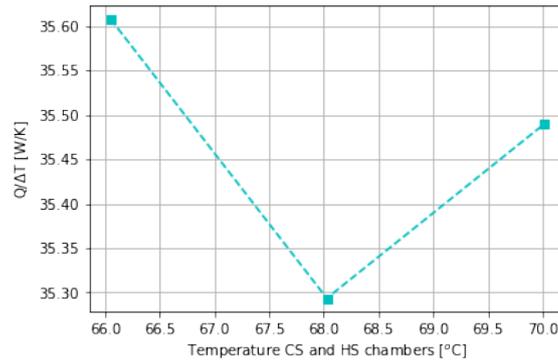


Figure 6: Results of calibration tests performed at CS and HS chambers.

Table 6: Results of experimental overall heat transfer coefficient

Wall analyzed	UA [W/K]	Overall heat transfer coefficient [W/(m <sup>2</sup> K)]
Partition wall	2,0 ± 0.1	0.358 ± 0.016
CS outer walls	16.4 ± 0.1	0.568 ± 0.005
HS outer walls	19.2 ± 0.1	0.843 ± 0.005

The differences between the theoretical and experimental overall heat transfer coefficients may be mainly related to the estimate of the convection coefficient when calculating the first one, to the heat leakage through the doors of the chamber and through the glass window, whose thermal conductivity was not considered in the theoretical calculus. The mainly objective of performing the calibration procedure is to determine the heat and energy exchanges listed above, considering the difficulty and imprecision of estimating it theoretically. From this point forward, the three experimental U are used to calculate the amount of heat transferred through the walls of the calorimeter during tests executed on it, according to the temperature difference between the three environments.

#### 4.2 AC capacity test

For the capacity test, the conventional AC was installed in the calorimeter and set to operate at maximum capacity mode. The main objective of this test is to compare the capacity, the consumption and the COP obtained for the same AC tested in the calorimeter from Polo Laboratories and in the one from the certified lab. In both calorimeters, the tests were executed keeping the CS with average temperatures of 17°C, 22°C and 26.7°C. The HS was always kept at 35°C and the OS at a constant temperature between 20°C and 25°C. In general, the ambient conditions presented at Tab. 5 were replicated, except the OS and HS humidity.

The temperatures for the tests performed with both calorimeters were defined based on the standards recommended conditions and on the objectives of the project. According to ISO-5151 (2017), it is recommended that, for moderate climates, the AC is tested with the CS chamber at 27°C and the HS chamber at 35°C. The 22°C test was performed due to the temperature that the magnetic air conditioning system, which will be tested at the calorimeter, is designed to operate at. Lastly, the 17°C temperature was determined in order to test the AC at larger temperature ranges, once this is the minimum CS temperature that steady state conditions could be reached with the AC and the calorimeter apparatus.

First of all, the consumption achieved with the tests performed at Polo and the other calorimeter can be compared in Fig. 7. The difference of consumption between the two calorimeters for the 22°C and 26.7°C tests are 29 and 20 W, respectively. However, for the 17°C test, a bigger difference, of 142 W, was obtained.

The capacities calculated based on the measurements from the calorimeters are depicted in Fig. 8. A capacity variation of  $0.52 \pm 0.07$  kW was obtained for the temperature range analyzed. This variation may be related to the adaptations defined for the calorimeter. Lastly, the results for the COP are found in Fig. 9.

A comparison of all results obtained is presented in Tab. 7. Since the HS chamber conditions are very similar for all tests performed and CS conditions follow the ones applied for the tests from the certified lab, it is estimated that the consumption and capacity errors of the calorimeter are mostly related to physical space restrictions, the absence of a complete control system for the three environments, measurement uncertainties and the installation of the AC device. Considering the increase of the deviation of consumption for lower temperature tests, almost 10 times higher than the percentage deviation at 26.7°C, other tests varying the CS temperature are necessary to have a more reliable relationship between consumption points and their errors.

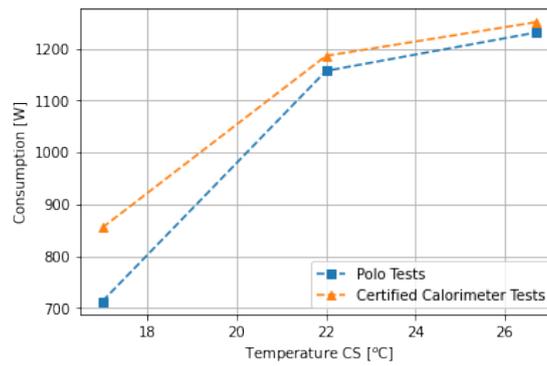


Figure 7: Consumption measured at capacity tests with Polo and certified lab calorimeters. Error bars could not be added due to the chart scale.

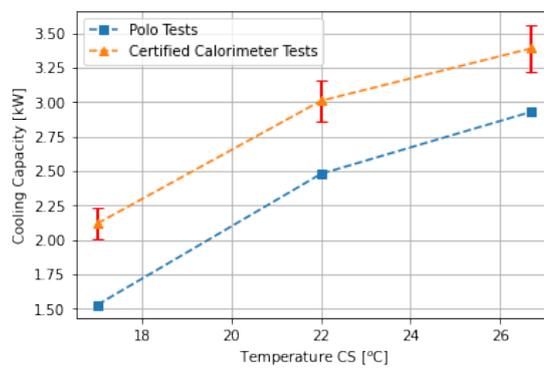


Figure 8: Cooling capacities calculated for tests performed with Polo and certified lab calorimeters. Capacity uncertainties for tests executed at Polo are shown at Tab. 7 and could not be added to the chart due to the scale.

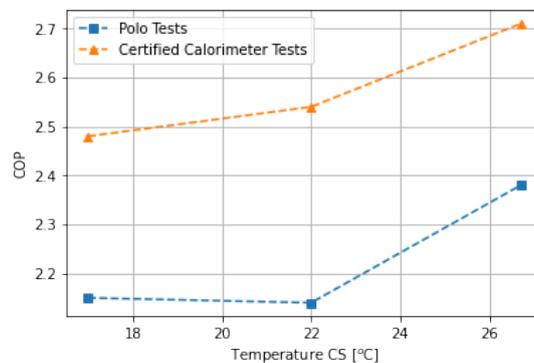


Figure 9: Results of COP of the AC tested in Polo and certified lab Calorimeters

Table 7: Results of the analysis of the conventional AC system

Variable	Polo Calorimeter	Certified Calorimeter	Deviation <sup>(1)</sup>
Cooling Capacity (17°C), kW	1.53 ± 0.01	2.12	38.5%
Cooling Capacity (22°C), kW	2.48 ± 0.02	3.01	21.4%
Cooling Capacity (26.7°C), kW	2.93 ± 0.02	3.39	15.7%
Consumption (17°C), W	713 ± 4	855	19.9%
Consumption (22°C), W	1157 ± 4	1186	2.5%
Consumption (26.7°C), W	1231 ± 4	1251	1.6%
COP (17°C)	2.14 ± 0.02	2.48	15.9%
COP (22°C)	2.14 ± 0.02	2.54	18.7%
COP (26.7°C)	2.39 ± 0.02	2.71	13.4%

<sup>(1)</sup> Referring to the value measured at Polo.

## 5. CONCLUSIONS

The main objective of this work is to design, assemble and evaluate a calorimeter, that meets requirements related to space, budget and equipment restrictions, in order to test a magnetic air conditioning systems designed at the laboratory. The calorimeter built at Polo is a calibrated calorimeter and, with current equipment, can be used to measure cooling capacity by the inlet chamber. With the comparison of results from testing a vapor compression AC with a certified calorimeter and with the one from Polo, it is possible to analyze the impacts of such modifications and considered it for future tests.

The calorimeter from Polo presents maximum deviation of 38.5% for capacity measurements, but for tests performed above 22°C the deviation reduces to equal to or less than 21.4%. The consumption presents a higher deviation for tests with CS temperature near the AC minimum temperature, but for the two other conditions, an average deviation of 2% from the reference values was obtained. The results of capacity, consumption and COP obtained at the tests with higher CS temperatures indicate that the apparatus is adequated to its main objective, which is to test a 9000 BTU/h magnetic air conditioning system with the CS at 22°C.

Tests varying the CS set temperature as well as replicating the procedures but at different calorimeters are recommended in order to increase the reliability of the results and the comparisons. Also, for future works, measuring the amount of heat absorbed by the chiller is a way to implement the energy balance at the HS and then confirm the capacity calculated by the analysis of the two chambers.

## 6. ACKNOWLEDGEMENTS

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## 8. RESPONSIBILITY NOTICE

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