Publishable summary

NANOCOOL project:

"An Energy Efficient Air Conditioning System with Temperature and Humidity independent controls based on the combination of a Liquid Desiccants Cycle with an adapted conventional air cooling system"

September 2012 – February 2016

PROJECT WEBSITE: http://www.nanocoolproject.eu/

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1. Executive summary

The objective of nanoCOOL project is to develop an innovative Hybrid Liquid Desiccant (HLD) Air Conditioning System with independent temperature and humidity control, where the latent load is removed by a liquid desiccant dehumidifier, while the sensible load is removed by a conventional air conditioning system. nanoCOOL project aims at reducing capital and operating costs of air conditioning systems, by developing a HLD system in which waste heat from the condenser is used for regeneration of the desiccants.

The project entails different steps in order to validate the HLD technology with the advances proposed. The first step has been the conceptual design of the HLD system, which comprises a liquid desiccant system and a conventional air handling unit adapted to fit it. The system is completed with a polyvalent unit, able to provide simultaneous heating and cooling to the different components of the HLD device. Secondly, the demonstration site has been defined, and the prototype has been sized according to the calculated thermal loads, by means of the thermodynamic models developed in the design phase.

In parallel, the research in nanomaterials for various components of the system has been carried out. This has been focused on the one hand on the development and upscaling of a plasma treatment for the improvement of wettability of polymeric tubes; and on the other hand, on the development and upscaling of composite materials, with graphene nano-platelets dispersed throughout a polymer matrix, for the improvement of thermal conductivity of heat exchangers.

The physical design of the whole system has been completed, and then the manufacturing of each of the parts and the final assembly has been carried out, to install the complete nanoCOOL system first in a laboratory. Besides, the control strategy has been designed and different control modes have been implemented. In the design, particular effort has been made on the use of materials which are corrosion resistant in the part of the desiccant system, and the inclusion of a polymeric knitted wire mesh demister able to prevent carryover of lithium chloride droplets to the rest of the system. Another key point considered during the design process is the capacity of the system to control independently temperature and humidity.

The complete system has been firstly tested in the laboratory, in order to set it up correctly, test the different working modes and control strategies; prior to its transportation to Taipei (Taiwan), where the demonstration site is located, comprising the locker rooms of a swimming pool in the Taiwan Building Technology Centre Campus.

During the demonstration period, the system has been operating continuously. Its ability to control independently temperature and humidity has been demonstrated, and energy savings of around 30% have been achieved, when compared to a traditional system. Moreover, increased quality of the indoor environment by suppression of unpleasant odors and an appropriate control of the humidity resulting in superior comfort and indoor air quality have been reported by the locker room users through comfort questionnaires.

Project results have been disseminated to relevant stakeholders throughout the project development. Furthermore, two international workshops have been organized in the scope of the project, for the results dissemination. Finally a Plan of Use and Dissemination of Foreground has been completed, and a Memorandum of Understanding for Exploitation has been accomplished.

2. Project context and objectives

Buildings account for 40% of final energy consumption globally and are an equally important source of CO_2 emissions. Currently, space heating and cooling as well as hot water are estimated to account for roughly half of global energy consumption in buildings. These end-uses represent significant opportunities to reduce energy consumption, improve energy security and reduce CO_2 emissions, due to the fact that space and water-heating provision is dominated by fossil fuels while cooling demand is growing rapidly in countries with very carbon-intensive electricity systems.

In air conditioning, humidity control and ventilation are equally important as temperature control, for maintaining Indoor Air Quality. Sick Building Syndrome has aroused as a consequence of poor ventilation or high humidity levels inside the buildings. This can be solved by improving the ventilation requirements; however in very humid climates, even if the required air changes are reached, the introduction of very humid air in the buildings can cause discomfort and unhealthy environments, easing mold growth for example.

Conventional compression air conditioning systems match the latent cooling loads by reaching the dew point of air, for water condensation (growth of mold and bacteria). Consequently, the air leaving the cooling coils is very cold and near the saturation point. For many applications, that temperature level just after the cooling coil is too low for an adequate thermal comfort, making necessary the posterior reheating of air, with the consequent increase in energy consumption. This process can be easily observed in a psychrometric chart. Figure 1 shows the cooling and dehumidification process with two different approaches. In the conventional process (red line), due to the need to reach the dew point for reducing humidity ratio, outlet temperature from the cooling coil is less than 10ºC, a temperature way too cold to be introduced to a conditioned space, and needs to be reheated. In the HLDS process (blue line), the humidity ratio is reduced without the need to reach the dew point, reaching a temperature closer to the comfort impulsion temperature.

Especially in very humid climates with low sensible heat ratio, it is difficult to meet the requirements of ventilation and match the sensible and latent loads in an efficient way. The sensible heat ratio represents the ratio of sensible heating or cooling load to total thermal load. In these cases the concept of free-cooling, i.e. the use of external air to lower the humidity and match the latent load, becomes difficult.

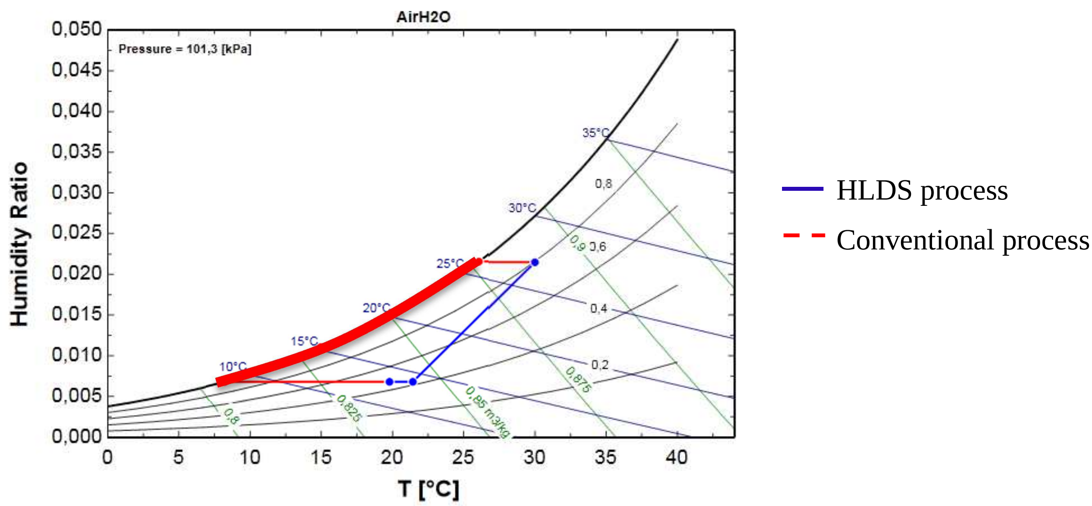


Figure 1. Comparison between a Hybrid Liquid Desiccant System and a conventional cooling and dehumidification

Liquid desiccant systems (LDS) are a promising alternative to compression cooling technology for the proper matching of the latent cooling loads without the need of cooling the air in excess. These systems rely on a hygroscopic solution which absorbs humidity from air, therefore being able to match the latent cooling loads without reaching the dew point of air. The solution used for absorption must be regenerated, and a heat source is needed for that purpose. The advantage is that thermal energy is used, which can be provided from renewable or waste heat sources, for example.

The desiccant used for the purpose of dehumidifying can be in liquid or solid form. Liquid desiccant systems show several advantages when compared to solid desiccants; such as lower pressure drop and regeneration temperatures, ease of manipulation, possibility of thermo-chemical storage, suitability of dust removal by filtration and suppression of unpleasant odors.

When combining the LDS features with the conventional compression cooling technology, a Hybrid Liquid Desiccant (HLD) system is created. These systems take advantage of the convenient dehumidification of the liquid desiccant, with the cooling by conventional compression technology.

Moreover, Hybrid Liquid Desiccant Systems are suitable as well for other applications where humidity control is of high importance, including food processing, hospitals, pharmaceutical industry, cleam rooms, ice rinks, etc.

As stated before, in conventional air conditioning systems the dehumidification and cooling process takes place simultaneously, by reaching the dew point of air, condensing and cooling the air at the same time.

In order to match the sensible and latent cooling loads, during the design process the sensible heat ratio is defined and HVAC systems are sized accordingly. However, the ratio of sensible load to total load can vary considerably inside a building, mainly due to changes in outdoor climate, occupancy, indoor equipment and lighting utilization, etc. This makes difficult an independent control of temperature and humidity. Moreover, the conventional air treatment process often leads inevitably to reheating the air.

For that reason, the development of systems able to control independently temperature and humidity is considered of high interest in the HVAC sector, and this is one of the main objectives of nanoCOOL project.

The major drawback of Liquid Desiccant Systems is the corrosiveness of the solution used as absorbent, generally lithium chloride. This can be detrimental to main construction materials, which makes it necessary to use expensive metals such as titanium, or especially protected materials for the machines.

For this reason the design is focused on plastic materials, resistant to corrosion. A major problem that the use of plastic materials has for the main two components of the system, the absorber and the regenerator, is the poor wettability properties of those materials. In falling film heat & mass exchangers, ensuring a complete wettability of the tubes is essential to have a good efficiency of the system, as dry patches lead to important reduction of performance. Therefore one of the identified objectives of the project has been the use of nanomaterials for the improvement of wettability of polymeric materials, with specific developments in this field.

On the other hand, thermal conductivity of polymeric materials is quite low when compared with metals. Hence, another important objective of the project is the development of polymeric matrix nanostructured compounds with higher thermal conductivity.

Additionally, the corrosiveness of the LiCl solution makes necessary the minimization of carryover of liquid out of the system, as the solution may corrode other parts of the installation (air ducts, etc.). Therefore, the avoidance of carryover has been another important objective of the project, focusing on the design of an effective demister for application in the HLD system.

Project Public Website:

The public website www.nanocoolproject.eu contains background information and has been up-to-date with results from the project.

List of partners:

- Tecnalia Research & Innovation: Project coordinator (www.tecnalia.com)
- SGL Group (www.sglcarbon.com)
- Airlan (www.airlan.es)
- Universitat Rovira I Virgili (www.urv.cat)
- D'appolonia (www.dappolonia.it)
- Politecnico di Torino (www.polito.it)
- Ridan (www.ridan.pl)
- Stam (www.stamtech.com)
- Fenix (www.fenixtnt.eu)
- Technion (www.technion.ac.il)
- Decsa (www.decsa.it)
- TBTC (http://www-e.ntust.edu.tw/)

Figure 2. nanoCOOL partners

3. Main S&T results. Foreground

Below, a synthesis of the main activities and scientific & technical results of nanoCOOL project is presented; starting from the conceptual design, the developments in the frame of nanomaterials, the detailed design, manufacturing, testing, and finally the demonstration phase and the achieved results in real operation.

Conceptual design. System requirements

The first stage of the project has been the conceptual design of the system. Since the beginning, the design has been aimed at a hybrid system, which combines:

- The liquid desiccant technology for matching the latent cooling load, which means removing humidity from air until required comfort conditions.
- The conventional cooling compression cycle for matching the sensible cooling load, which means cooling down the air until required comfort conditions.

The nanoCOOL prototype has been sized for its operation in the locker rooms of a swimming pool in the Taiwan Building Technology Center in Taipei. This application is characterized by a high internal humidity generation, low sensible heat ratio, and high external humidity levels due to sub-tropical humid climate present in Taiwan.

Based on the design conditions, the internal sensible and latent heat generation, and the ventilation requirements according to international standards; the design conditions and the cooling and dehumidification loads have been calculated, as well as the annual sensible and latent cooling loads, as shown in Table 1 and Figure 3.

Outdoor design conditions	30ºC / 21,5 g/kg dry air
Comfort design conditions	24ºC / 7,5 g/kg dry air
Ventilation rate	2.500 m^3/h
Internal sensible heat load	3,5 kW
Ventilation sensible heat load	5 kW
Total sensible heat load	8,5 kW
Internal latent heat load	8,8 kW
Ventilation latent heat load	21,3 kW
Total latent heat load	30,1 kW

Table 1. Design conditions and cooling and dehumidification loads

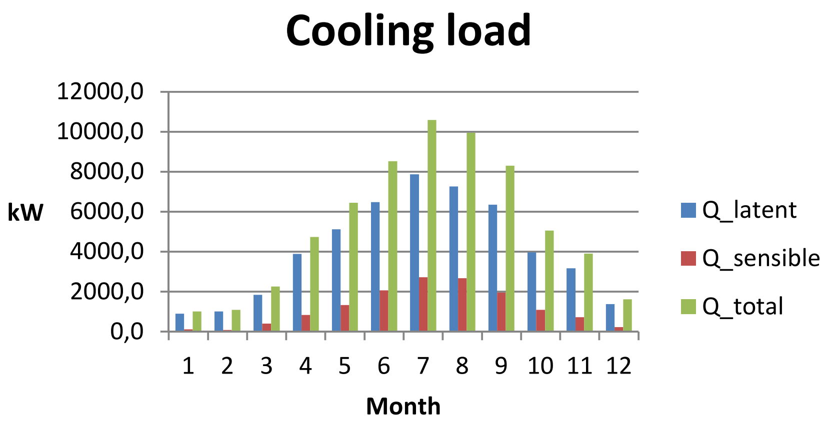


Figure 3. Annual sensible and latent cooling loads

The designed Hybrid Liquid Desiccant (HLD) system is comprised by a Liquid Desiccant System (LDS) whose main components are the absorber, regenerator and liquid-liquid heat exchanger; and a conventional Air Handling Unit (AHU) with a cooling coil and a cross-plate heat exchanger for ventilation heat recovery. A polyvalent unit able to simultaneously provide cooling and heating, feeds the absorber and the cooling coil with cold water at around 15ºC, and the regenerator with hot water at around 55ºC.

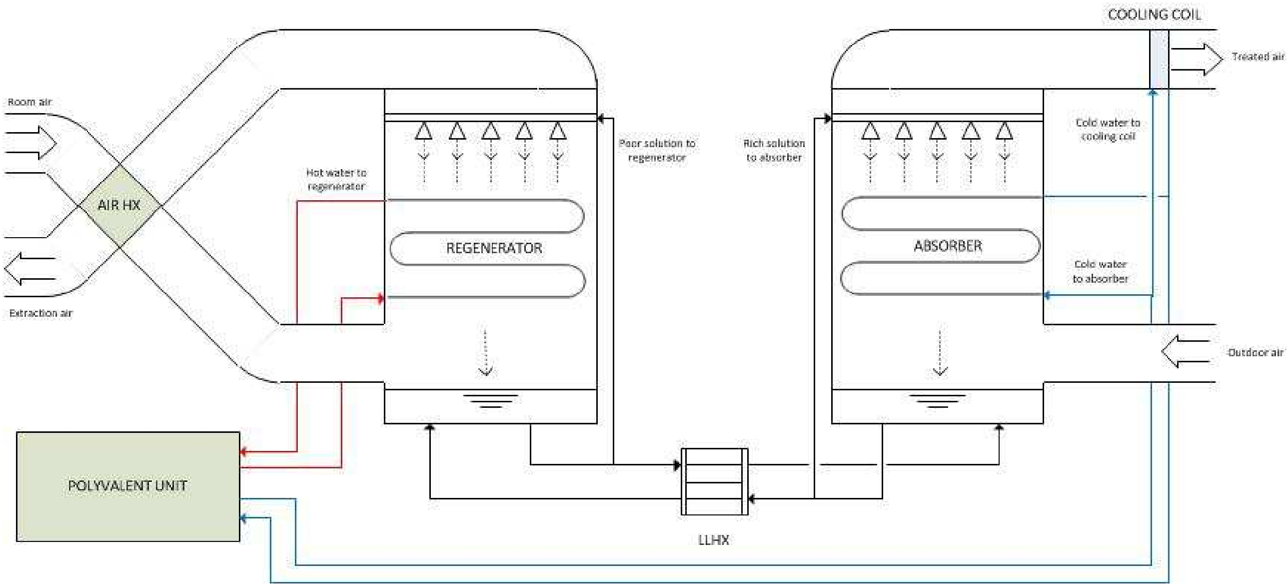


Figure 4. Scheme of the complete nanoCOOL HLD system

Nanomaterials for heat exchangers

Liquid desiccant systems often have corrosion problems, as the used lithium chloride solution is highly corrosive. As common metals can be easily corroded, plastic materials are used for the liquid desiccant part. One drawback of the use of plastic materials for the absorber and regenerator, is the poor wettability of tubes, which is a key parameter in falling film heat & mass exchangers.

This is why one of the goals of the project has been the development of nano-thin layers by means of plasma treatment for wettability improvement of polymeric tubes.

On the other hand, the use of nanomaterials can be beneficial for improving the thermal conductivity of some materials. For this reason, the development of polymeric matrix nanostructured compounds has been investigated, by the combination of graphite and polypropylene with nanoplatelets of graphene; for the improvement of the thermal conductivity of the liquid-liquid heat exchanger.

Plasma treatment for improvement of wettability of heat & mass exchanger tubes

Two different approaches have been developed for the improvement of wettability, namely by plasma deposition or by deposition of nanolayers from aqueous suspensions of polyelectrolites (layer by layer technology). Full wettability has been obtained with both approaches, but plasma treatment results so far in the highest coating durability, this is why it has been chosen as the method for the wettability improvement of tubes.

By plasma technique, different deposition and polymerization methods for acrylic acid have been tested on 3 different polymers as substrate. Results showed in all cases a radical change in the surface wettability by the LiCl solution, with contact angles in the range between 30º to less than 10° after treatment.

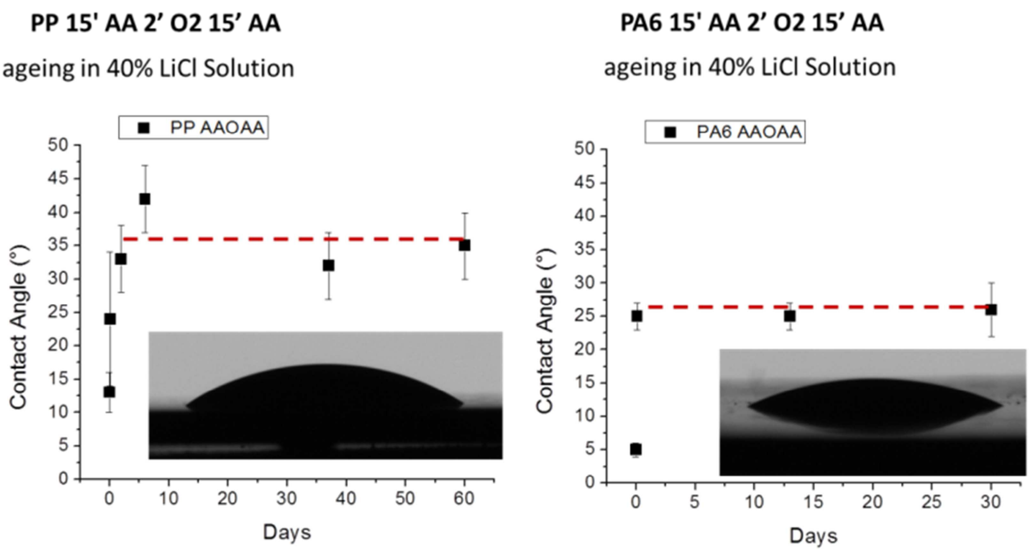


Figure 5. Contact angle of LiCl 40% solution in different coated polymeric materials.

These contact angles result in full wettability of surfaces when used in continuous flow of LiCl solution, as in the absorber/regenerator exchangers.

After the treatment of individual tubes, the upscaling of the process to a continuous ambient pressure plasma torch deposition system has been carried out. This way, large quantities of tube can be continuously treated, easing the process when a large batch of tubes is needed, as in the case of the tube bundles of the absorber and regenerator of nanoCOOL system.

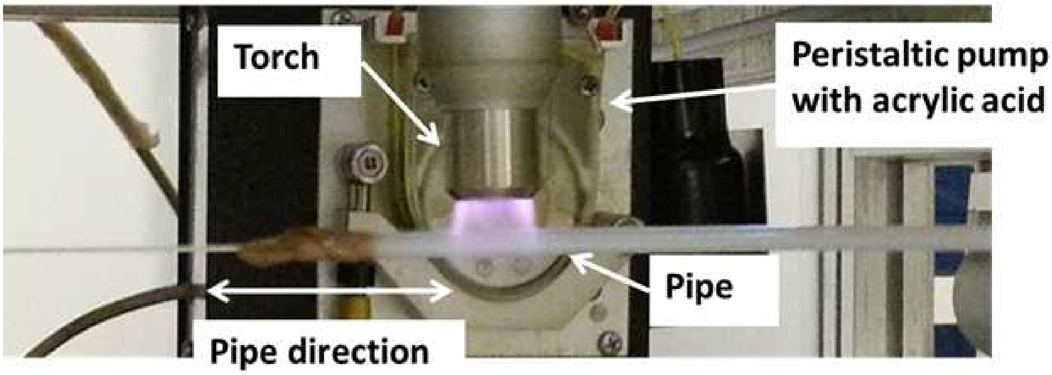


Figure 6. Atmospheric pressure plasma torch for continuous plasma treatment to tubes

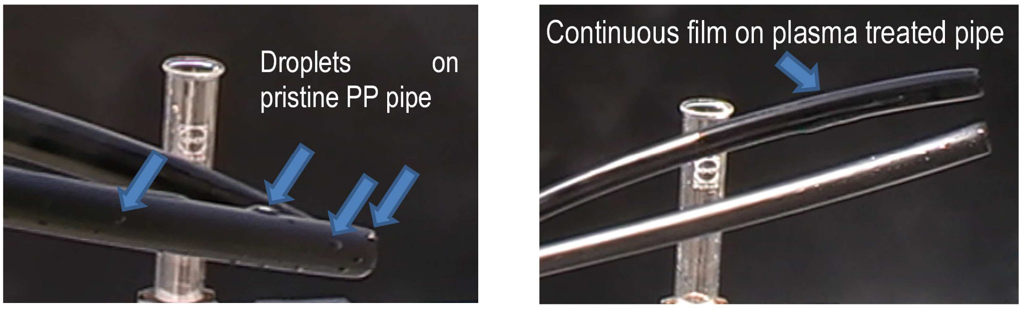


Figure 7. Wettability comparison between untreated and atmospheric pressure continuous plasma treated PP pipe. (water 30w% LiCl)

Plasma treated tubes were used to manufacture the proof of concept heat & mass exchangers to be tested at laboratory scale. After comparison of wettability behavior with both proof of concept heat exchangers (treated and untreated), plasma treatment was proved to deliver a better performance, from wettability point of view, compared to standard polypropylene tubes, enhancing the heat and mass transfer coefficients.

Figure 8. Falling film proof-of-concept heat/mass exchanger.

The plasma technology transfer from lab scale to pre-industrial scale (10 km batches) was carried out.This activity was particularly challenging owing to the several parameters affecting the deposition and the intrinsic difficulties in the surface characterization of the nanometric-thick layer.

Another activity which has been carried out includes accelerated ageing tests of the plasma treated tubes, in order to check their durability over time. The tests consist on having the treated tubes with solution flowing externally over them continuously, at a higher temperature than the operating temperature in nanoCOOL system. Results from this test show that the wettability gained thanks to the plasma treatment is not completely maintained over time, which will result in a loss of capacity of the system.

Development of nanostructured compounds for improvement of thermal conductivity of heat exchanger

Different graphene nanoplatelets have been selected and used as nanofillers for thermally conductive polymer nanocomposites. Using Graphene Nano-Platelets (GNP) as such, moderate improvements of thermal conductivity have been achieved, owing to the defectivity degree of commercially available graphenes and severe difficulties in dispersion by melt blending. Two different methods for the improvement of GNP by pre-dispersion in liquids have been developed and demonstrated beneficial, despite limitations apply in their industrial application.

On the other hand, the combination of graphite and graphene has demonstrated synergistic effect in terms of thermal conductivity, leading to a formulation which can be applied to the liquid-liquid heat exchange in the nanoCOOL system. However, this PP/graphite/GNP nanostructured microcomposite solution will inevitably have to compete with more conventional PP/graphite composites. Especially the cost of the GNP, still in the range of hundreds of €/kg, and the limited industrial availability clearly affects the industrial exploitation at present.

The nanostructured compounds which have been developed are included in the solution-solution heat exchanger constructed for the prototype of nanoCOOL system.

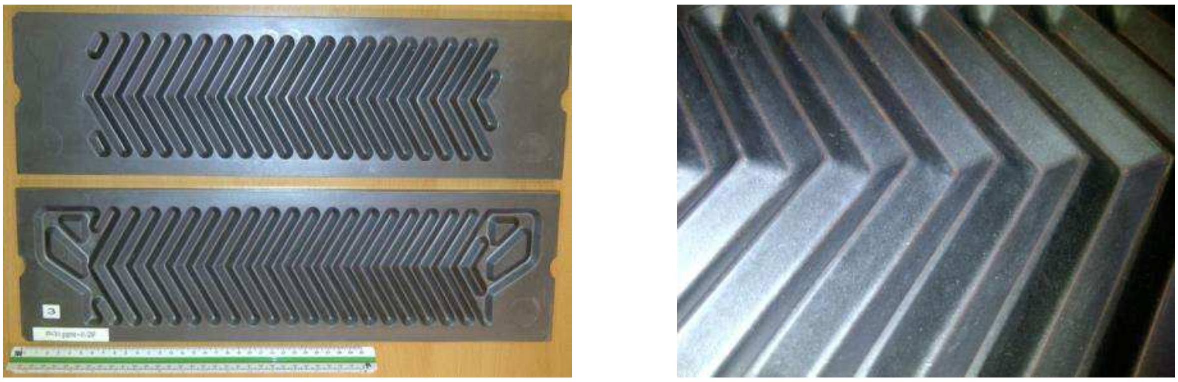


Figure 9. PHE plate made of 22% PP, 74% Graphite and 4% GNP

Design and manufacturing of nanoCOOL system

The designed hybrid liquid desiccant system (HLDS) is comprised by a liquid desiccant system (LDS) whose main components are the absorber, regenerator and liquid-liquid heat exchanger; and a conventional Air Handling Unit (AHU) with a cooling coil and a cross-plate heat exchanger for ventilation heat recovery. A polyvalent unit able to simultaneously provide cooling and heating, feeds the absorber and the cooling coil with cold water at around 15ºC, and the regenerator with hot water at around 55ºC.

Liquid desiccant system (LDS)

The absorber and the regenerator are falling film type heat&mass exchangers, internally cooled and heated respectively. They are comprised by a treated polypropylene tube bundle, a liquid distribution system based on spray nozzles, and a demister inside a fiber glass tower. Tube bundles are formed by individual modules of tubes, which are linked horizontally in groups of three, and then vertically to form several passes. Proper wettability of tubes is a key factor for obtaining good performance in the liquid desiccant cycle, for that reason, as previously explained, the polypropylene tubes have received a plasma treatment in order to improve their wettability.

The air flows from bottom to top getting in contact with the descendent lithium chloride solution, which forms a falling film outside the tubes. The rich LiCl solution absorbs humidity from the air in the absorber, meanwhile the poor LiCl solution desorbs humidity enriching the solution in the regenerator. Cold (15ºC) and hot water (55ºC) flow inside the absorber and regenerator tubes, respectively, cooling the solution and the air during the absorption process (exothermic reaction), and heating the solution and the air during the regeneration process (endothermic reaction).

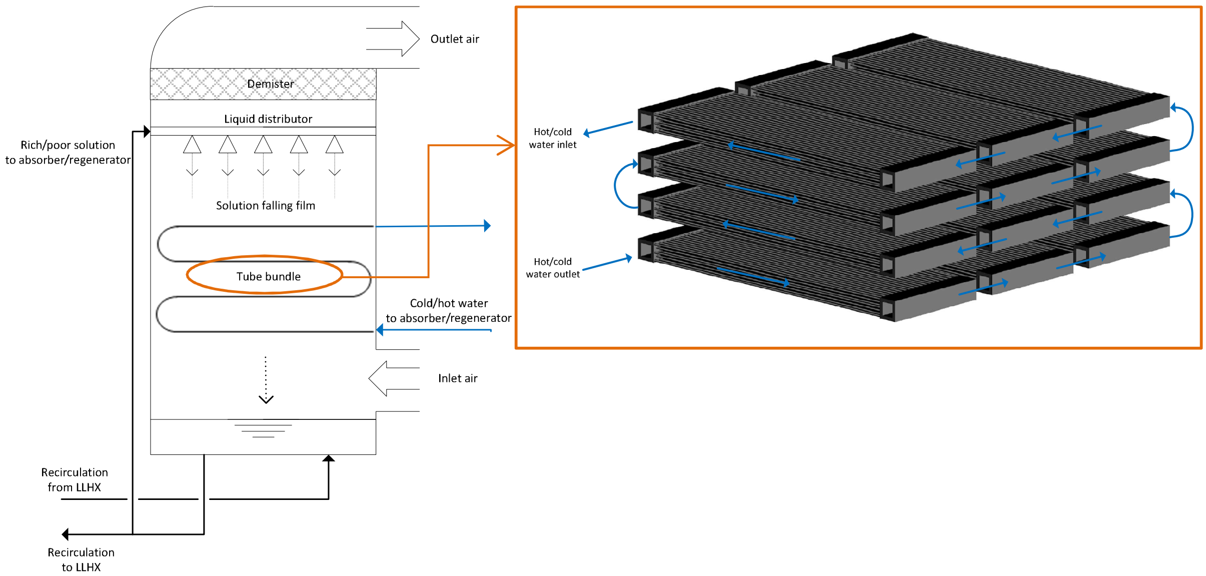


Figure 10. Scheme of the absorber/regenerator units, and the tube bundle layout

Figure 11. Tube bundles of the absorber and regenerator heat & mass exchangers

On top of the absorber and regenerator towers, there is the demister, a polypropylene wire-mesh device aimed at avoiding LiCl solution carryover to the rest of the system and the air distribution installation. Below the demister, the distributor and the nozzles which spray the LiCl solution over the tube bundles are located.

Figure 12. Distributor with nozzles (left) and demisters of the absorber and regenerator towers (right)

The demister has been specifically designed for the purpose of avoiding carryover of lithium chloride to the rest of the system, as it can cause considerable damage, due to it corrosivity. Different kinds of wire-mesh has been selected, focusing on having low pressure drop and higher droplet separation effectiveness.

The liquid-liquid heat exchanger is a plate heat exchanger made of a polymeric matrix composite including graphene nanoparticles. It is used to precool the solution going to the absorber, and to preheat the solution entering the regenerator.

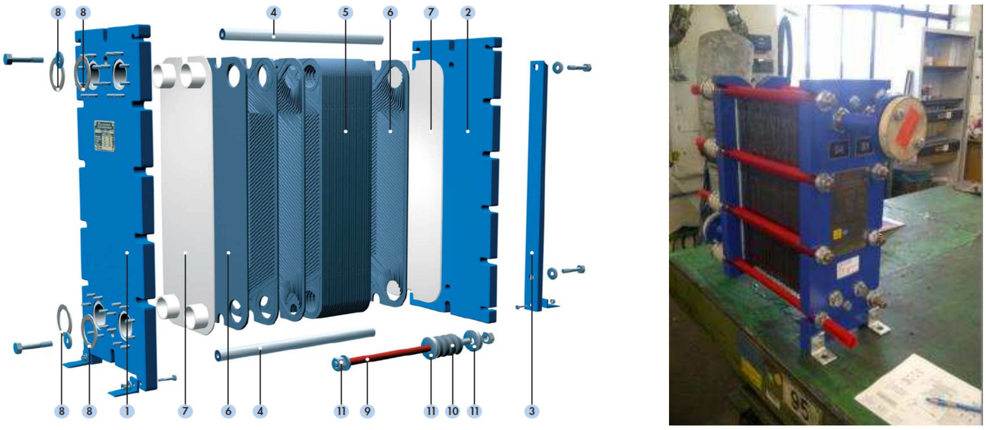


Figure 13. Liquid-liquid heat exchanger included in the nanoCOOL prototype

Air Handling Unit (AHU)

The air handling unit comprises the air plate heat exchanger for heat recovery of ventilation, the cooling coil, and the corresponding fans, dampers and filters for the system. The casing and the arrangement of the different elements is specially designed for its optimal connection with the LDS.

The extended surface cooling coil has a serpentine arrangement of multipass tube circuits, and in the case of nanoCOOL system, it will only take care of the sensible cooling or heating loads. It has been oversized to be able to match the total maximum sensible cooling load, although in design conditions it will have a much lower capacity.

The air heat exchanger is a compact plate heat exchanger, with cross-flow configuration, made of aluminium and with internal fins to increase the heat transfer between both air streams. The use of such equipment enables considerable savings to be achieved in the operating costs of air-conditioning plants, and thus the saving of energy that would otherwise be lost. In the HLDS it is used for preheating the air entering the regenerator.

Figure 14. Cooling coil


Figure 15. Air plate heat exchanger

Polyvalent Unit (PU)

The polyvalent unit is a heat pump able to provide heating and cooling simultaneously, by recovering the heat of condensation through water condenser when the machine is working on dual mode, and dissipating condensation heat to the air when the machine is working on cooling mode. Therefore, it is used in cooling mode when the LDS is only dehumidifying and cooling (regenerator off), or in dual mode when the system is regenerating LiCl solution as well, with no need from another external source of heat. The selected polyvalent unit corresponds to a frequency of 60 Hz because of the electric power supply in Taiwan.

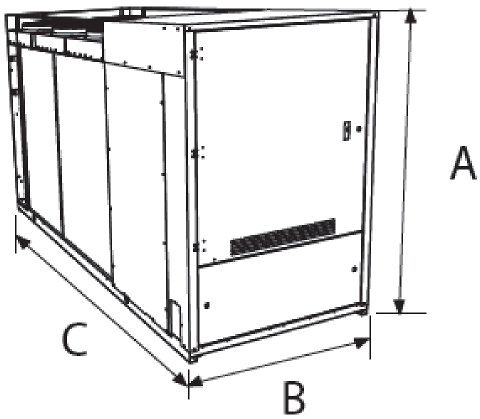


Figure 16. Polyvalent unit

Complete system design and construction

Apart from the main components detailed before, the rest of the components of the system have been selected, including the measurement sensors. Also the design of the LiCl solution circuit (connecting absorber and regenerator through the solution-solution heat exchanger in the LDS), and the hydraulic circuit (connecting the PU with the absorber, regenerator and cooling coil in the HLD), have been carried out.

Furthermore, the electrical scheme of the prototype has been developed, taking into account that the electric power supply in Taiwan is three-phase 230 V and 60 Hz.

The complete nanoCOOL system including all its components, sensors and actuators, is represented in a Piping and Instrumentation Diagram (P&ID), which has been continuously updating until the ultimate design version (see Figure 17).

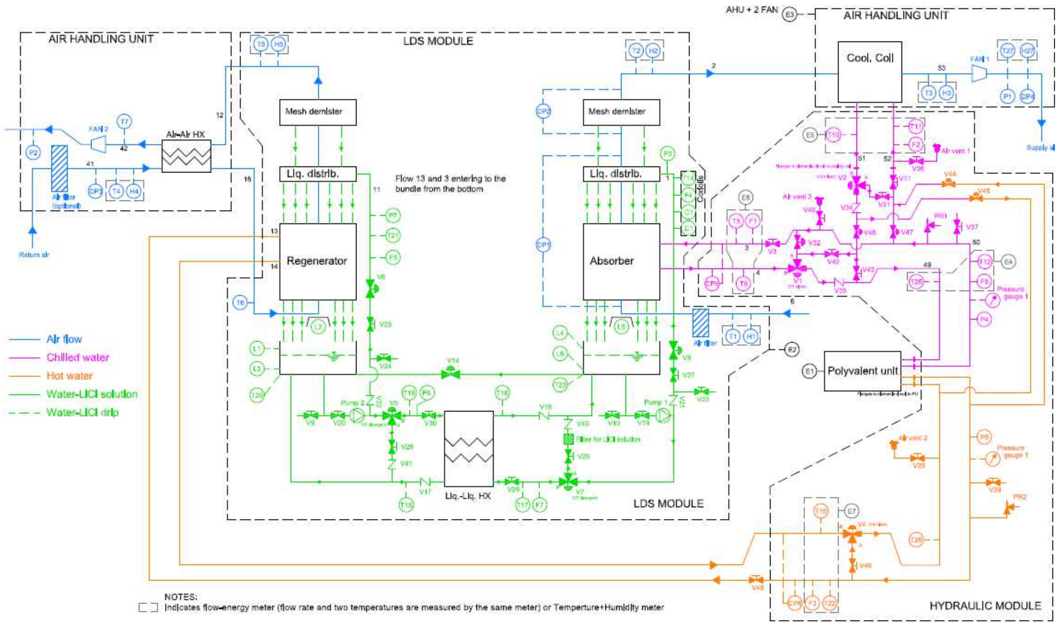


Figure 17. nanoCOOL overall architecture

For the design, rating and simulation of the system, detailed thermodynamic models of the main components (absorber, regenerator, liquid-liquid heat exchanger) of the LDS have been carried out. Based on developed component models a complete thermodynamic model of the LDS, and the whole HLD system, has been carried out. For a specific geometrical configuration of the system (absorber, generator, solution-solution heat exchanger, air-air heat exchanger and cooling coil) and with fixed working conditions given by supply and return air temperature and humidity conditions, cold/hot water supply temperatures and flow rates and LiCl solution's flow rate; the developed model returns as a result: air, solution and hot/cold water outlet conditions, and thermal loads of absorber, regenerator, solution-solution heat exchanger, cooling coil, and air-air heat exchanger. For the absorber and regenerator thermodynamic models, heat and mass transfer coefficients of an experimental set-up with a titanium heat exchanger have been considered, assuming similar wettability of plasma treated polypropylene tubes.

The model is also useful for determining the pressure drop in the solution air and water circuits, which is necessary for sizing several components of the system.

Once the model is validated with experimental results, it is valuable for sizing installations of different thermal capacities, for future designs. This way, it is possible to size a new system based on the design conditions (climatic and air impulsion conditions), or to rate an existing system with different working conditions from the design ones.

Finally, a 3D CAD design of each of the elements, and the complete nanoCOOL system has been developed, as well as the executive drawings prior to the construction of the system. For the off-the-shelf components, 3D or 2D drawings from the manufacturers have been used, but mainly the design has been customised for the specific requirements of the hybrid liquid desiccant system.

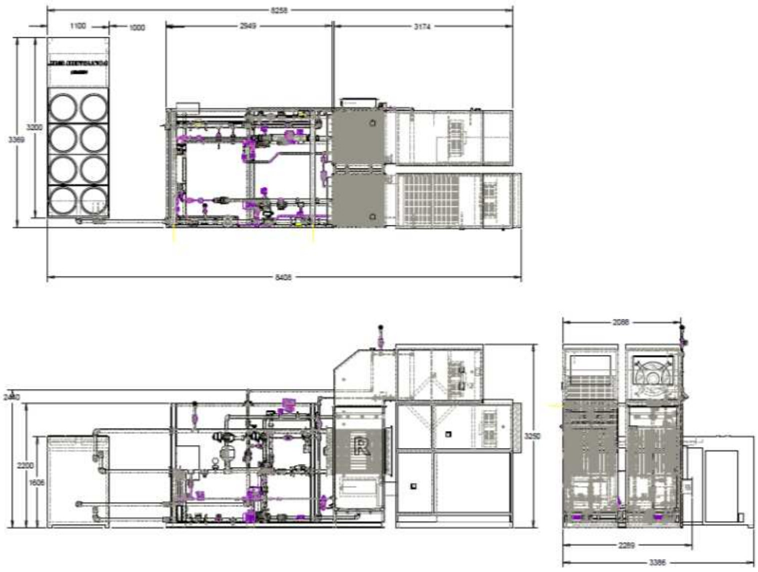


Figure 18. nanoCOOL prototype dimensions

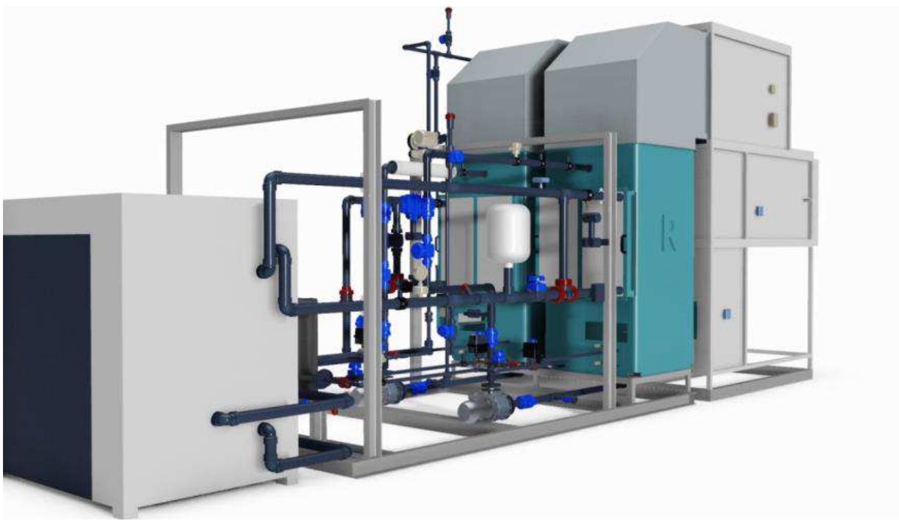


Figure 19. Isometric view of the nanoCOOL prototype

The system has been constructed in two stages. First the LDS construction took place in Italy, from where it was transported to Spain. The next step was the AHU and hydraulic circuit construction. The combined system plus the polyvalent unit where then transported to another location in Spain, where the installation in the laboratory was completed, including the link between the hydraulic circuit and the polyvalent unit.

Figure 20. LDS construction in Italy

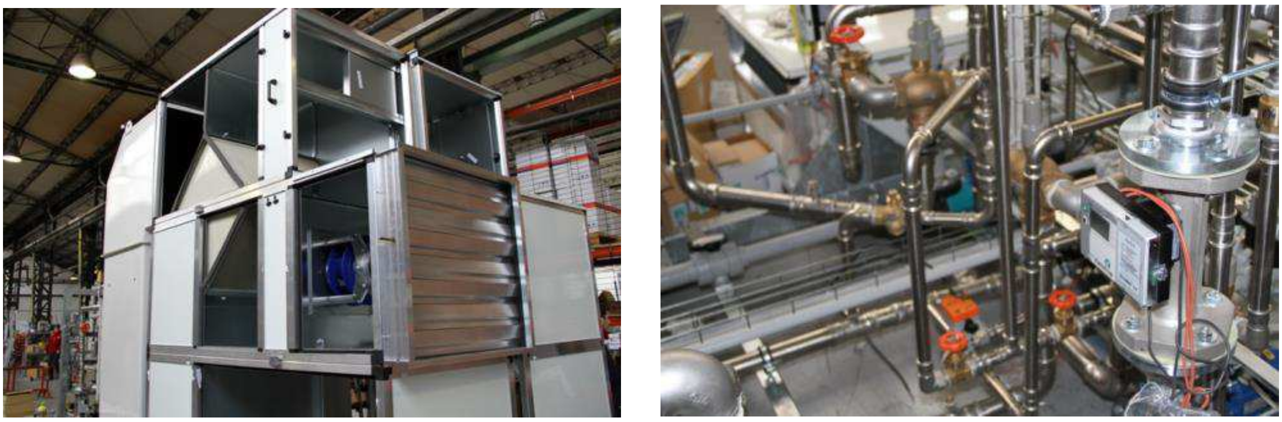


Figure 21. AHU and hydraulic circuit construction in Spain

Control system

In parallel to the physical design of the nanoCOOL system, the control algorithm has been developed. The purpose of the control algorithm is to ensure a reliable operation of the prototype, taking care of the possible malfunction during the operation and controlling the main variables of the system to maintain the comfort conditions (temperature and humidity) in the conditioned space. An important feature of the system is the independent control of temperature and humidity, which has been considered in the control algorithm definition.

The operation of the absorber is related to the dehumidification requirements while the operation of the cooling coil is related to the temperature set point required in the conditioned space. The operation of the regenerator depends on the liquid desiccant operation. The objective of the regeneration process is to maintain the LiCl solution concentration between some levels in order to guarantee the dehumidification capacity in the absorber. The operation of the regenerator can be continuous or intermittent as a function of the dehumidification requirements and the selected strategy to control the regenerator. Several strategies with different options have been implemented in order to select, during the testing phase, which is the best strategy to control the regenerator. These control strategies have been experimentally tested in the laboratory, as well as in the demonstration site, in order to choose the final control strategy of the system, in order to ensure an adequate operation during its lifetime.

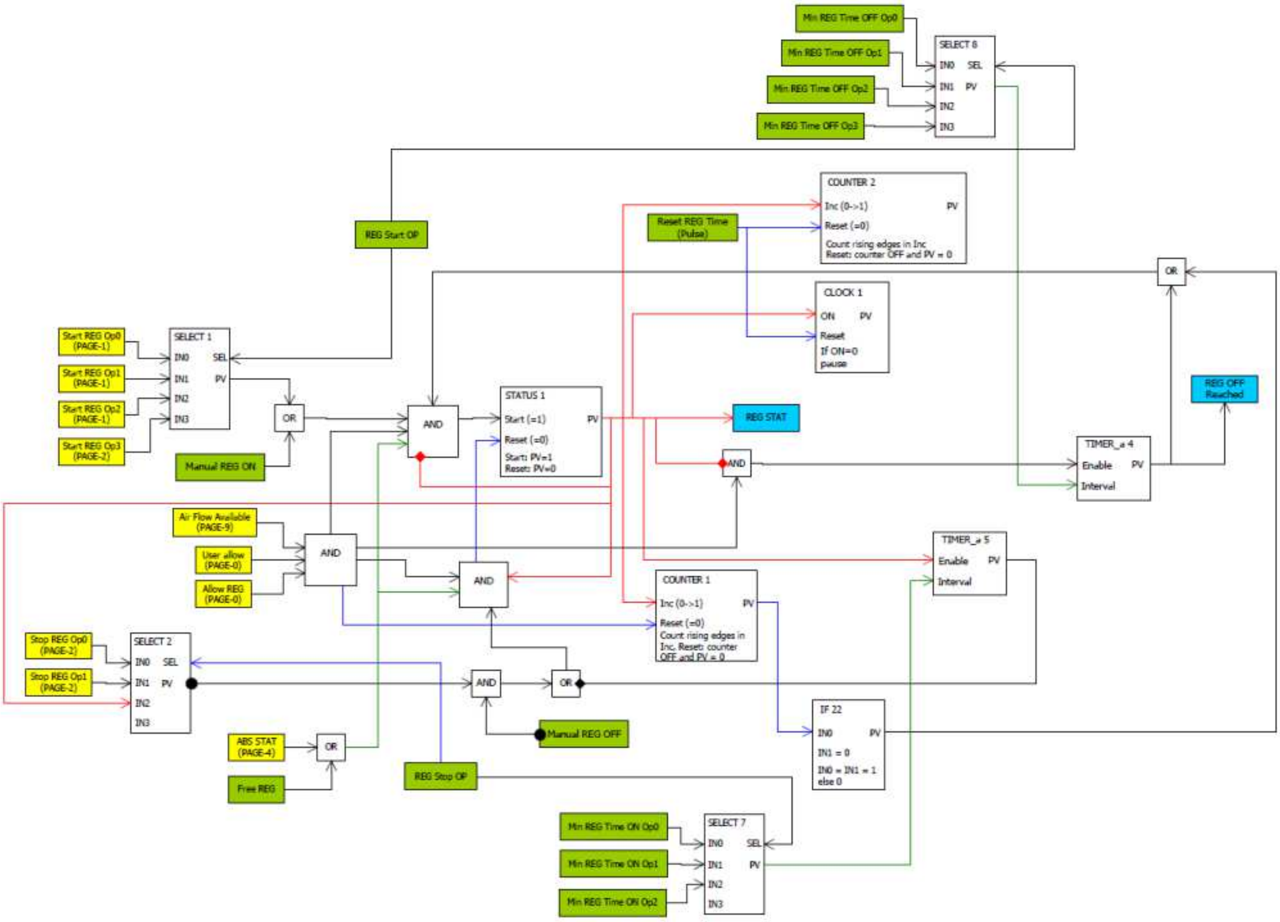


Figure 22. Block diagram showing the start/stop permissions for the regenerator

Testing and demonstration in real conditions

As explained before, final assembly including the link of the HLD system and the polyvalent unit was made in a laboratory. The objective of the testing period has been to correctly set-up the system, test different working modes, and analyze measured data for performance calculation and optimization.

The following activities have been carried out in the laboratory:

- Testing of the nanoCOOL system in manual and automatic modes according to the type tests previously defined.
- Installation of a first version of the monitoring system.
- Carryover and air quality tests.
- Data acquisition and performance analysis.
- Calculation of heat and mass transfer coefficients and validation of the models.

Figure 23. Installation of the nanoCOOL system in the laboratory

The laboratory has been prepared in order to emulate the same conditions of operation of the nanoCOOL system in the demonstration site. In order to achieve moist air at tropical conditions for the absorber’s supply air stream a gas boiler that provides hot water to an Air Handling Unit (AHU) , a steam generator and a humidifier are used. On the other hand room conditions are achieved by using a chiller that provides cold water to another AHU.

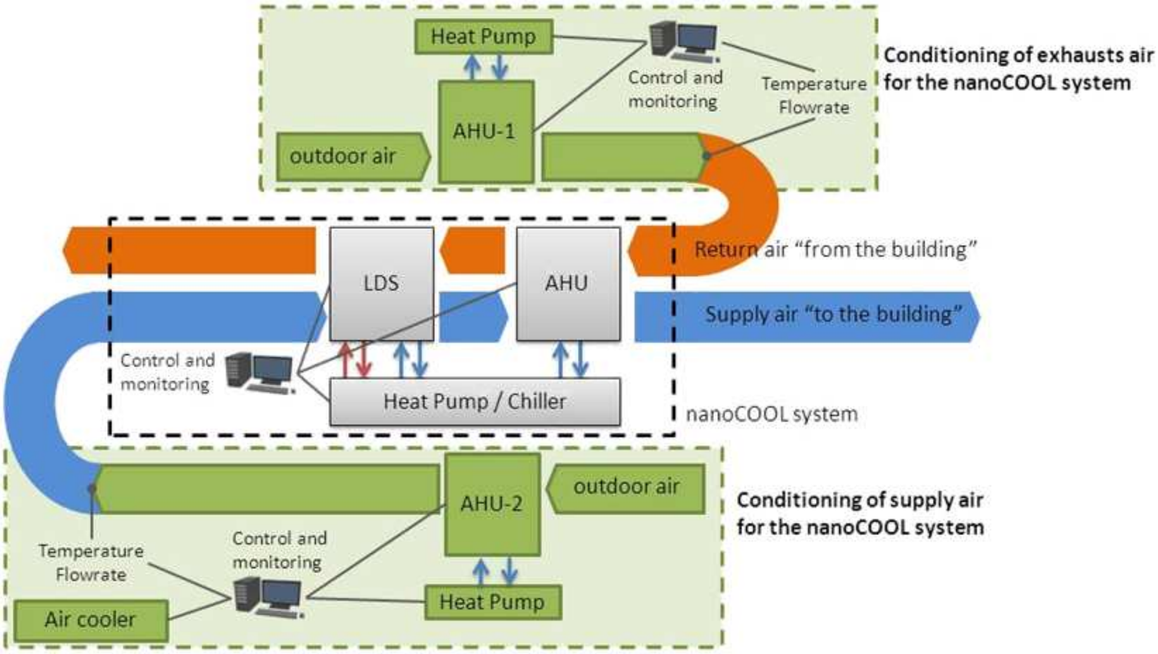


Figure 24. Test bench + nanoCOOL system conceptual scheme

First, functional tests have been carried out, in order to set-up the subsystems, and set maximum and operation flow rates, make adjustment of manual valves, recalibration of the required sensors, check leaks, pressure tests, etc. Then, a set of manual tests has been developed, in order to test operation modes and set control parameters. Finally, a step by step checking of the control algorithm has been carried out and once it has been fine-tuned, the automatic tests with different control modes have been completed.

Obtained results from a representative period of time have been used to calculate heat & mass transfer coefficients and validate the developed thermodynamic model of the nanoCOOL system. Also the first calculation of performance has been done; attaining Total COP (coefficient of performance) values of around 3. The Total COP has been defined as:

$$Total\_COP\_h = \frac{Q\_total\_h}{PUActiveEnrgy_{t0} - PUActiveEnergy_{t0-60minutes}}$$

For the cooling effect the load of the absorber and the cooling coil are summed, accounting for the latent (dehumidification) and sensible (cooling) loads. The energy consumption considered is the one of the Polyvalent Unit, as the rest of the installation (air distribution system, etc.) is not the same as in the final installation (Demonstration Site).

An important output in this stage has been the carryover measurement. It is crucial to avoid lithium chloride carryover, as it is a highly corrosive salt which can cause considerable damage to different parts of the machine if it escapes from the absorber/regenerator, as well as to the distribution air ducts. Two individual methods have been used independently for the determination of lithium chloride concentration in the air stream:

- Lithium measurement: Flame Atomic Absorbtion Spectrometry (FAAS)
- Chlorides measurement: UV/VIS Spectrophotometry

The results showed that carryover values fall well below most restrictive exposure limits (5 mg/m^3).

On the other hand, the concentration of particulate matter in the air was measured, being one of the key factors contributing to air quality. In each of the measured conditions, the volume of the dust meets the requirements of the maximum dust concentrations in respect to the Ambient Air Quality Standards for the European Union, defined in the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe12 which defines the value of 50 µg/m^3 (24 hours averaging period) ad 40 µg/m^3 (1 year) in PM10 dust and 25 µg/m^3 in case of the PM2.5 dust.

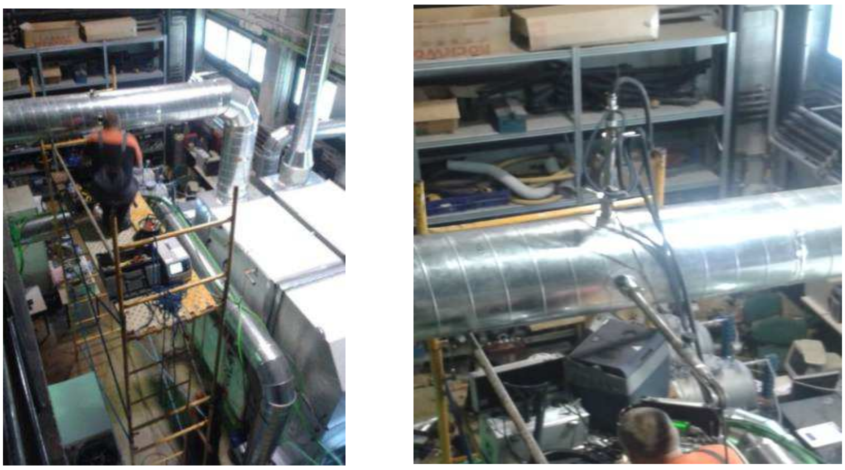


Figure 25. Carryover measurement

After the laboratory tests stage, the nanoCOOL system has been transported by ship from Spain to Taiwan, in order to be installed in the demonstration site, the locker rooms of a swimming pool in the Taiwan Building Technology Center in Taipei (Taiwan). The nanoCOOL system travelled by sea from Barcelona port to Kaohsiung port in Taiwan, and then by road to Taipei.

Figure 26. Dismantling and containerization of the nanoCOOL system in Spain, for its transportation to Taipei

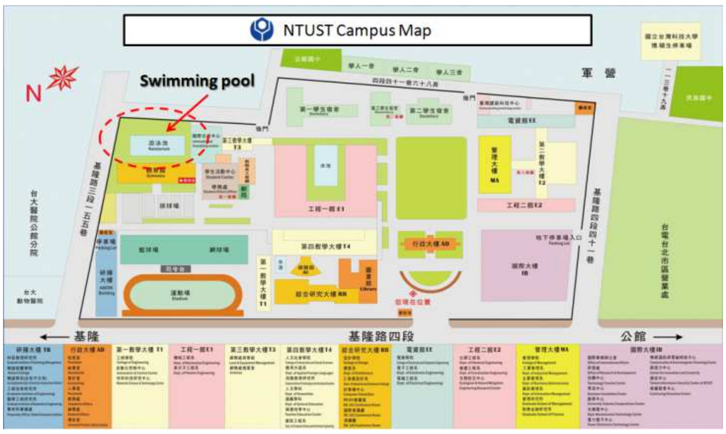


Figure 27. Pilot plant overview (Taipei, Taiwan)

The nanoCOOL system has been installed in a terrace, adjacent to the locker rooms of the swimming pool. The site has been prepared for the commissioning of the system. A lay out design of the system has been prepared in advance, taking into account both the dimensional restrictions of the terrace and the distances that should be respected for the proper performance maintenance of the system. Besides, the existing climatic conditions in Taiwan make necessary to install a protective roof above the unit. A fence has been also designed to limit the passing of unauthorized users. The system also required the installation of dampeners, in order to minimize the effects of possible vibrations to the building.

In order to provide treated air to the locker rooms, two air ducts have been installed between those and the nanoCOOL system, located in the terrace; one for the supply air to the locker rooms and the other one for the return air from the locker rooms. Their dimensioning was established considering the nominal air flow rate, a proper air velocity defined by normative and the structural constraints of the building.

A variable air flow rate installation is chosen for the best possible independent control of temperature and humidity. In each zone, an independent controller regulates a damper to control the supply air flow rate as a function of the temperature in the zone. The fan of the AHU is controlled to maintain a constant supply air pressure. The supply temperature is constant and the humidity is controlled in the return air stream. With this regulation, each zone requires a damper in the main supply and return air duct.

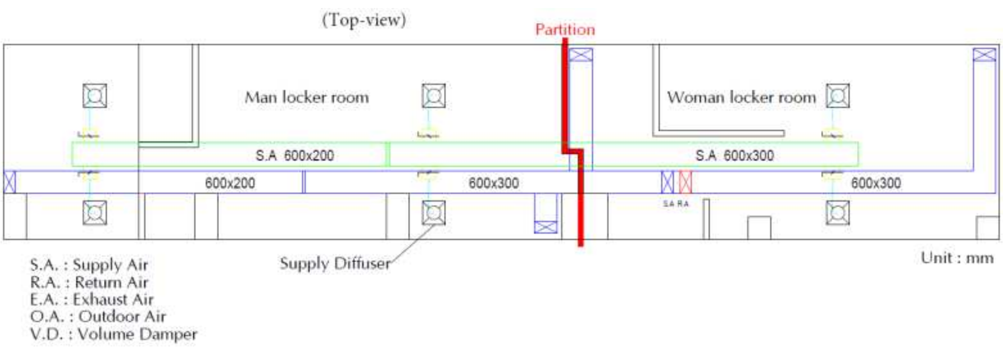


Figure 28. Air distribution system from the terrace to the locker rooms

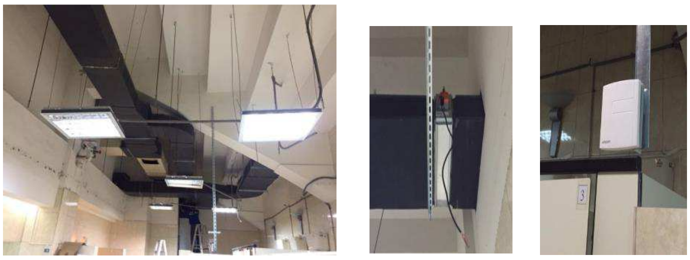


Figure 29. Air ducts installation, damper and sensor

For the installation of the nanoCOOL system in the demonstration site, a modification of the hydraulic circuit was proposed, including a water accumulation tank and an additional pump and two-way valve in each of the circuits (hot and cold circuits), between the polyvalent unit and the hydraulic circuit of the HLD system. These tanks provide inertial load, impeding that the PU starts or stops working many times in short periods of time, reducing the life span of this equipment.

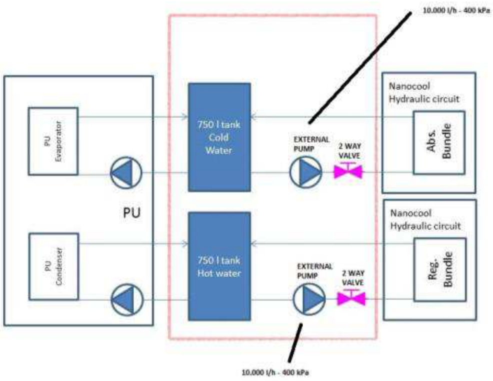


Figure 30. Scheme of the modifications included in the hydraulic circuit.

Figure 31. NanoCOOL system installed in the demonstration site

After the nanoCOOL system installation, the commissioning of the system has taken place, starting with functional manual tests in each part of the system, focusing specially in the new parts of the installation:

- Air distribution system and dampers, temperature and humidity sensors placed in the locker rooms.
- Upgraded Hydraulic circuit with new water circulation pumps and buffer tanks, for the revision of possible leakages, pressure tests development, drainage of air, and adjustment of manual valves.

These functional tests helped to identify some problems which could be solved, for the successful setting up of the system to work in automatic mode. Once the commissioning process was finished, a schedule was programmed for an automatic start-up of the nanoCOOL prototype, taking into account the swimming pool calendar.

The system includes a monitoring and control system that act at different levels, each of which is characterized by different time requirements and calculation power. The actual control of nanoCOOL is performed by the control system (PLC) and the SCADA software. Such system is physically installed in the demo and allows supervisory control and data acquisition even remotely. It is characterized by real time behaviour; high reliability and availability; and a relative poor calculation power, tailored on the system necessities. Although the SCADA includes the storage of data, the limited calculation power and memory, and the present security issues make impossible to satisfy the need for data analysis at a satisfactory level.

The Monitoring System is conceived to be able to retrieve the available data from the SCADA, store them in a larger database and making them accessible on-line, without interfering with control.

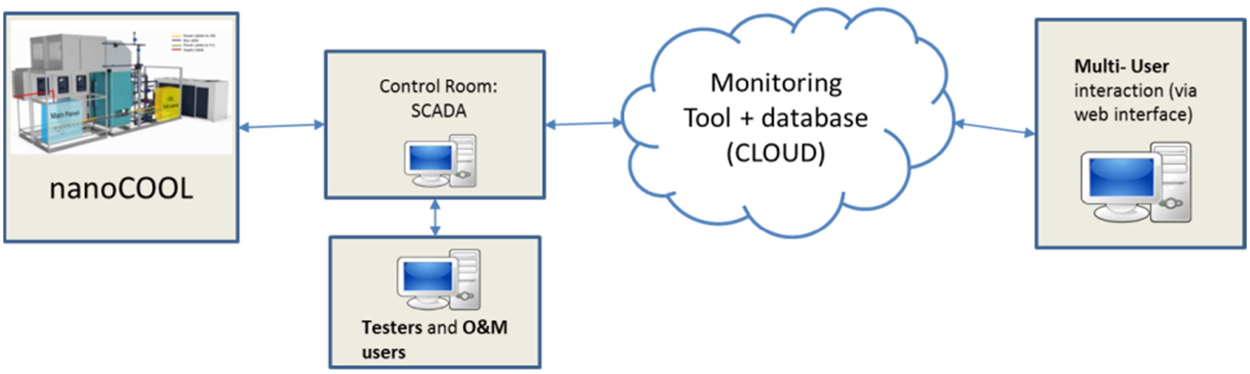


Figure 32. Architecture of control and monitoring system

The instrumentation and actuators installed in nanoCOOL are used and controlled by the local PLC, responsible of valves regulation, temperatures and flow rates control. The PLC is connected by Ethernet cable to the SCADA system, in charge of measurement retrievement and high level control (it allows the facility manager to select the operational mode, to set a weekly time table, to directly control the actuators, etc). The on field values sent by the PLC are stored in a database.

The SCADA has a secure interface to internet, so to allow the Monitoring System, hosted in a cloud service, to periodically download the measurement data. To avoid any external intrusion, the connection between SCADA and Monitoring System is made through a VPN.

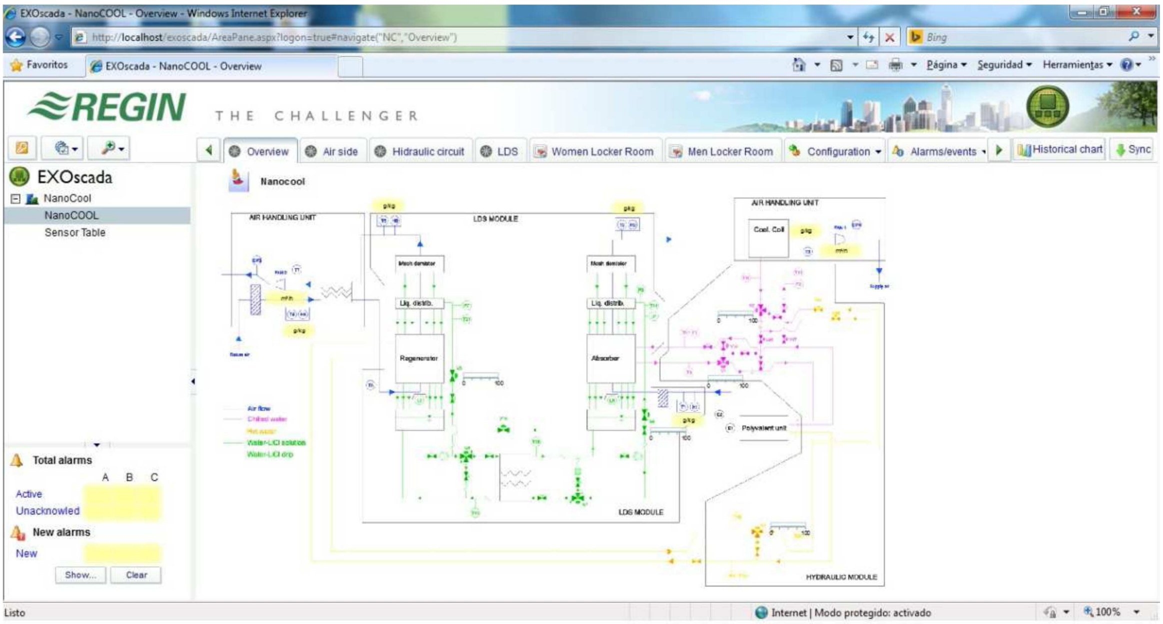


Figure 33. Scada of the nanoCOOL system

The monitoring system consists on a web-based tool with different functionalities:

- Selection of individual parameters and list of parameters to be plotted in charts
- Customizable plot ranges and dates
- Export function of the selected data into a downloadable Microsoft Excel file
- Calculation of Key Performance Indicators (KPIs)

The calculated KPIs include:

- Instantaneous values
    - Saturation pressure
    - Absolute humidity
    - Enthalpy
    - Air density
    - Air flow rate

- Cooling and heating power

- Hourly values
  - Cooling and heating energy
  - COP values for the whole system, for PU and LDS

The nanoCOOL monitoring system is accessible with the following URL address: http://nanocool.ridan.pl

Figure 34 and Figure 35 show screenshots of the monitoring system main menu and the selection and visualization of charts.

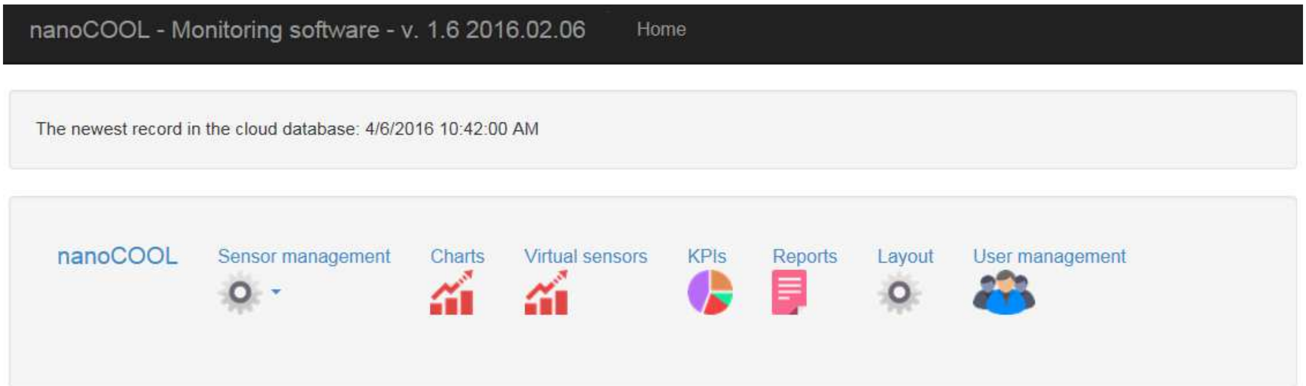


Figure 34. nanoCOOL monitoring web-based tool: Main menu

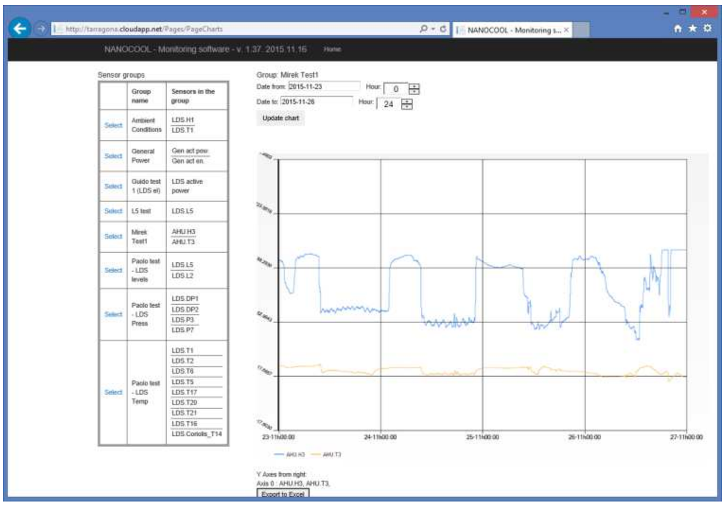


Figure 35. nanoCOOL web-based tool: Selection and visualization of charts

The system has been continuously running from November 2015 to February 2016, those four months are considered the monitoring period. After the project end in February 2016, the system continues working and monitoring data, for further analysis. The partners had reach an agreement to continue nanoCOOL system monitoring for a period of at least two years from the end of the project.

One of the main objectives of nanoCOOL system is to achieve successfully independent control of the temperature and humidity. For evaluating this feature of the system, data from different operation days have been analyzed. According to the analyzed results, nanoCOOL system shows an adequate independent control of temperature and humidity.

In days at full load, the system does not seem to reach the set point values, but the values are maintained below the maximum levels fixed in the control system, so they are corresponding to acceptable comfort levels. It must be taken into account that the system has been sized for a design point which has been exceeded during monitoring period. This is allowable for an air conditioning system.

At partial loads, nanoCOOL system regulates correctly to maintain humidity and temperature set point values, and the further is working from the design values, the most variations in the supply conditions occur to reach the set point values, with variation of the coil operation between cooling and heating mode intermittently. It is clear that the further weather conditions from the design values, the worse is going to be the COP of the system.

The independent control of temperature and humidity is successfully achieved, for many different ambient conditions faced by the system.

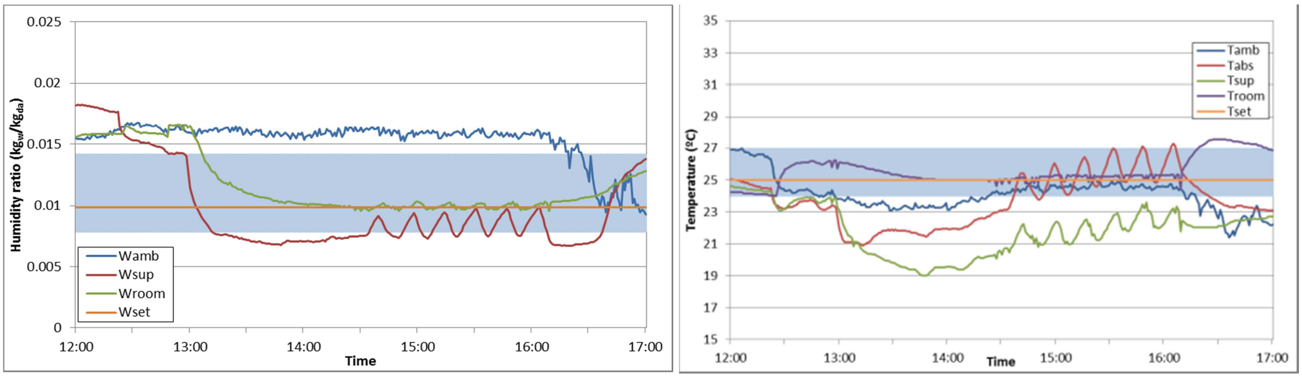


Figure 36. Temperatures and humidity ratios in the HLDS during a day with medium humidities and temperatures.

Different control strategies have been tested during the monitoring period. A thorough analysis of the data coming from the real values of the monitoring system has been developed in order to compare the experimentally tested control strategies in demo site. In order to do that, the evolution of ambient conditions and the internal and ventilation loads have been considered in order to find the most suitable days in which each of the strategies could be fairly compared.

From this comparison, it is concluded that the best control strategy for a proper accomplishment of the temperature and humidity set points, is to have the regenerator working all the time. The other alternative was to use the regenerator intermittently depending on the density values of the lithium chloride solution.

For the operation period, the values of the Coefficient of Performance (COP) have been calculated, achieving values of the Global COP of around 1,5. The Global COP is defined as:

$$Global\_COP\_h = \frac{Q\_total}{GeneralActiveEnergy_{t0} - GeneralActiveEnergy_{t0-60minutes}}$$

For the cooling effect, the load of the absorber and the cooling coil are summed; this accounts for the latent (dehumidification) and sensible (cooling) loads. Energy consumption comprises the general active energy consumed by fans, pumps, sensors & actuators, control boards and rest of peripherals.

It should be noted that the value of the Global COP is different from the Total COP calculated during the laboratory testing period, in which the energy consumption taken into account was the one of the polyvalent unit only. In the case of the demonstration site, the global installation has been taken into account, considering energy consumption of all the system, which includes electrical consumption associated with the air impulsion and return.

Based on the measured data in the pilot plant, an extrapolation of the whole year energy consumption has been carried out, in order to compare it with a traditional air conditioning system and evaluate the achieved energy savings. This comparison is included in the Life Cycle Analysis (LCA) and Life Cycle Costing Analysis (LCC) carried out.

The monitoring campaign on the pilot plant in Taipei allowed performing the energetic, economic and environmental assessment based on real data. The collected data have been used to calibrate the theoretical energy model of the nanoCOOL system and compare it with a traditional air conditioning system.

The calculation has been performed on a single year basis and then scaled up to the whole operational life of the system in the LCA and LCC analyses.

For the nanoCOOL system the calculation is based on the monitored data. The compatibility of average hourly weather conditions in Taipei with the monitored data available was checked and the consumptions for the whole year were set up interpolating the available information with respect to external air temperature and humidity, as well as the estimated occupancy level.

Regarding the traditional HVAC system, the energy consumed is calculated theoretically since there is no plant to monitor. The traditional system is comprised by an Air Handling Unit fed by cooling water and heating water from two different heat pumps. The modelling equations used traditionally by HVAC designers and the characteristic curves of heat pumps for Energy Efficiency Ratio (EER) and COP, are included in the calculations.

Based on the performed calculations, thermal energy savings of around 50% are calculated, with around 30% electric consumption savings. If renewable or waste heat were used, these savings would be even higher. These results are based on the comparison of extrapolated data of the measurements in the demonstration site, and the simulated energy consumption of a tradicional HVAC system, over an entire year. During the demonstration period, nanoCOOL system faced different climatic conditions, which have been considered representative of the conditions which can occur in all the seasons. For that reason, the measured data have been extrapolated to calculate energy consumption over a year.

Calculated electrical savings are lower than energetic savings for two reasons:

- The presence of auxiliary devices in the nanoCOOL, not present in the traditional case (salt solution pumps)
- The different working conditions of the heat pumps (lower power set-points are characterized by lower COPs)

Moreover, the environmental impact of nanoCOOL system was calculated, using the LCA approach according to international standards ISO 14040:2006 and 14044:2006. Obtained results show that nanoCOOL solution contributes to a lesser extent the environmental impact in terms of Primary Energy Demand, Global Warming Potential, Acidification Potential and Photochemical Ozone Formation.

The possible release of LiCl constitutes the major drawback of nanoCOOL and more in general of Liquid Desiccant Systems; especially with regards to Ozone Depletion Potential (ODP) and Freshwater Eutrophication Potential (FEP).

It was already well known since the beginning of the project that LiCl carryover must be minimized. This salt, although non-toxic, may have undesired impacts if not controlled:

- Corrosion of metals in metalic components downstream, such as rest of conventional HVAC systems, air distribution systems, etc.
- Ozone Depletion Potential and Freshwater Eutrophication Potential.

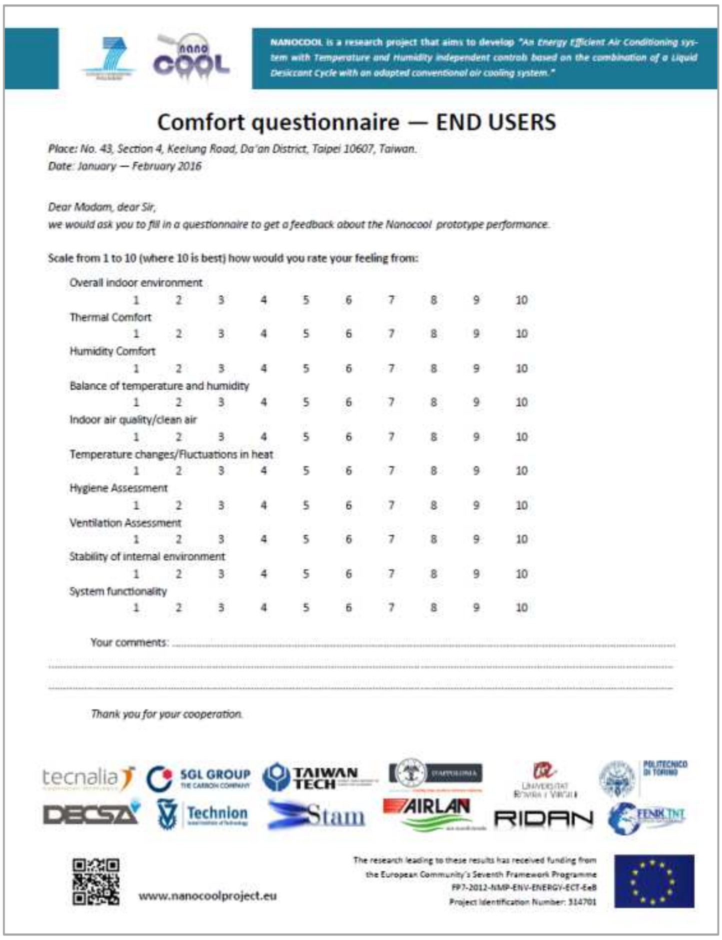
The deep effort in developing the appropriate demister, minimized the problem without exceeding the pressure losses and therefore the AHU fan consumptions. The principal recommendation of the current study is therefore to never underestimate the LiCl carryover problem: the exploiter will have to keep using the filtering technology already developed in nanoCOOL and will have to conceive all possible ways to contain LiCl leakages during manufacturing.

During the demonstration period, a set of questionnaires was completed by users of the facilities, in order to have their feedback in terms of thermal comfort, assessment of humidity levels, hygiene and ventilation, perceived Indoor Air Quality, and system functionality.

The received feedback from users is very positive, having a general high punctuation; and many positive comments with regards to the decrease of humidity levels in the locker rooms, increased thermal comfort, and reduction of odors.

Another set of questionnaires was prepared and completed by installers, in terms of the comfort, but also for evaluation of the installation and maintenance. The main concern of the installers was the maintenance of the system.

For that purpose the correspondent maintenance guidelines, recommendations and references have been provided from the nanoCOOL consortium to the installers and maintenance responsibles.



NANOCOOL is a research project that aims to develop *"An Energy Efficient Air Conditioning system with Temperature and Humidity independent controls based on the combination of a Liquid Desiccant Cycle with an adapted conventional air cooling system."*

Comfort questionnaire — END USERS

Place: No. 43, Section 4, Keelung Road, Da'an District, Taipei 10607, Taiwan.
Date: January — February 2016

Dear Madam, dear Sir,
we would ask you to fill in a questionnaire to get a feedback about the Nanocool prototype performance.

Scale from 1 to 10 (where 10 is best) how would you rate your feeling from:

Overall indoor environment
1 2 3 4 5 6 7 8 9 10
Thermal Comfort
1 2 3 4 5 6 7 8 9 10
Humidity Comfort
1 2 3 4 5 6 7 8 9 10
Balance of temperature and humidity
1 2 3 4 5 6 7 8 9 10
Indoor air quality/clean air
1 2 3 4 5 6 7 8 9 10
Temperature changes/Fluctuations in heat
1 2 3 4 5 6 7 8 9 10
Hygiene Assessment
1 2 3 4 5 6 7 8 9 10
Ventilation Assessment
1 2 3 4 5 6 7 8 9 10
Stability of internal environment
1 2 3 4 5 6 7 8 9 10
System functionality
1 2 3 4 5 6 7 8 9 10

Your comments: ....

Thank you for your cooperation.

www.nanocoolproject.eu

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7-2012-NMP-ENV-ENERGY-ECT-EeB Project Identification Number: 314701

Figure 37. Comfort questionnaire sample (end users)

Conclusions. Achievements of nanocool system

1) Energy savings
nanoCOOL project has achieved its main objective: the development of a hybrid liquid desiccant air conditioning system able to independently control temperature and humidity, and energetically efficient. Energy consumption of the system during the monitoring period (November 2015-February 2016) has been extrapolated to a whole year analysis, and compared with a traditional system for the same purpose ; showing thermal energy savings of 50%, and electrical savings of 30%, when compared to the simulation of a traditional HVAC system for a period of one year.

2) Independent temperature and humidity control
This goal has been fulfilled, as according with the operational behaviour during the monitoring period in the demonstration site, nanoCOOL system operates automatically controlling independently temperature and humidity of the conditioned space.

3) Improvement of air quality

   Related with the previous point, air quality in terms of comfort has been significantly improved, with the possibility to control temperature and humidity to the desired set points in the conditioned space. Related with this, the questionnaires filled by the users show a high degree of satisfaction related to the system operation.

   On the other hand, the concentration of particulate matter in the air has been measured in the laboratory, being one of the key factors contributing to air quality. In each of the measured conditions, the volume of the dust meets the requirements of the maximum dust concentrations in respect to the Ambient Air Quality Standards for the European Union. Besides, lithium chloride is known by its antibacterial properties, which results in cleaner and safer air. However, this property has not been measured during the operational period.

4) Carryover avoidance. Corrosion under control

   Lithium chloride carryover must be avoided, as it can cause corrosion of metals in metalic components downstream, such as rest of conventional HVAC systems, air distribution systems, etc. This is one of the goals of the design, which has been successfully achieved, confirmed by measurements of LiCl content of the air downstream of nanocool system, showing values lower than the most restrictive exposure limits.

5) Development of nanomaterials for wettability and thermal conductivity improvement

   One of the objectives which has been partially achieved is the development of nanomaterials for two purposes: wettability improvement and thermal conductivity increase in heat&mass exchangers. Developed plasma treatment has shown an improvement of the wettability of the tubes in the heat&mass exchangers; however this property is not completely maintained over time. This results in a loss of capacity of the system when compared to the design values. Regarding the improvement of thermal conoductivity, the inclusion on grapheme nanoplatelets in the plate heat exchanger has shown an improvement; but the application of this technology in a cost effective way is not achievable for the moment.

4. Potential impact. Dissemination activities and exploitation of results

Potential impact

Applications benefiting from HLD systems (nanoCOOL), fall into three categories: those that require low humidity, require high ventilation (especially in humid climates), or present a high internal latent load. Spaces requiring cool, comfortable conditions and low dew points (below 10ºC) or low relative humidity (30-50%) benefit from liquid desiccant systems.

Supermarkets, operating rooms, some commercial or industrial processes, and ice rinks are prime candidates for improved performance using this approach. Health care facilities, schools, and hotels all have high occupant density and correspondingly high ventilation requirements. Laboratories require ventilation to eliminate toxic chemicals. These buildings especially in humid climates, can greatly profit from HLD systems.

ASHRAE best practice design standards call for separate equipment to treat ventilation and/or latent loads. Finally, spaces with a high internal humidity load such as indoor pools, health clubs, and food processing facilities have high moisture removal requirements that cannot be easily and efficiently achieved with conventional equipment.

For decades, liquid desiccant technology has been a small player in the HVAC market, but with more focus on energy conservation and improved air quality, interest has rapidly increased. In the last few years companies such as Advantix Systems, Kathabar, and 7AC are offering these products. As such, the number and variety of applications using liquid desiccants is growing rapidly.

In the HVAC domain there are 2 standard desiccant technologies: Solid Wheel Desiccants and Conventional Vapor Compression Units, the LDAC (Liquid Desiccant Air Conditioning) technology boasts some key advantages over them:

1) Unlike conventional air conditioning systems, liquid desiccant systems directly absorb humidity from the air while cooling. This reduces energy consumption, by eliminating the need for over-cooling and reheating the air or regenerating the solid wheel.

2) Liquid desiccant systems also offer the ability to independently control temperature and humidity. This capability is beneficial for a wide range of applications including laboratory clean rooms, electronic chip manufacturing, in which very particular ambient conditions are required.

3) LDAC systems remove approximately 91% of the airborne microorganisms and 80% of particles larger than 5 microns in a single pass. This capability is crucial for a wide range of applications including food processing, hospitals, and pharmaceutical industry.

4) Liquid desiccant systems can be powered by renewable energy sources such as solar panels and geothermal water or by waste heat from co-generation systems. In this case, a competing technology is absorption cooling, which is known to be effective when coupled to solar energy.

5) HLD systems are adequate for applications in which frequent fluctuations of the sensible heat ratio (ratio of sensible load to total load). If the sensible heat ratio changes very frequently, this is problematic for traditional systems. nanoCOOL system can cope with these variations more easily, with an adequate independent control of temperature and humidity.

Unfortunately the HLD systems niche has never reached the popularity of the standard technologies because of two key facts:

1) Complexity and lack of knowledge: The liquid desiccant technology is unfamiliar to engineers and designers who install HVAC equipment, and to the traders that install and maintain it.

   In nanoCOOL this problem has been partially solved thanks to the adoption of non adiabatic towers, i.e. heat exchangers that integrate two thermodynamic processes in one (absorption/ desorption and cooling / heating).

2) Carry over and corrosion: Lithium chloride produces corrosion problems downstream leading to shorter lifespan of equipment.

   In nanoCOOL this problem has been solved with success thanks to the wide adoption of wettable plastic components and a successful and proved demister solution.

nanoCOOL system has been able to overcome the second drawback of HLD systems, by succesfully avoiding carryover of lithium chloride, thanks to the use of specifically designed demisters.

However, the main drawback encountered at the end of the project, is that presently the system is not cost-effective, when compared to traditional HVAC systems. Usually, traditional HVAC systems are designed as plug-and-play systems. nanoCOOL system requires specific hydraulic cirucit design for different installations, meaning additional costs and effort for design, pre-testing and commissioning.

The main impact in terms of socio-economics of the nanoCOOL development, considering technology itself, and the potential exploitation, is mainly related with the concept of independent control of temperature and humidity. This fact can activate several technological adaptations of the concept developed in the project to specific markets with critical demands of one or both of these parameters control requirements.

Humidity is a parameter usually controlled indirectly through the cooling process, which implies very important inefficiencies, and that can be improved drastically with the technology developed in the project. The independent management of temperature and humidity opens a relevant market for specific business that can be relevant in the near future, with potential activity in main economic sectors, as automotive, aerospace, or many industrial activities as industrial dryers, agro food sectors, etc.

It is also relevant to say that humidity is a key factor on the comfort of people, which can be useful to change the perception of comfort without altering any other condition.

These facts allow to say that beyond this project, there is a relevant potential impact in terms of society and economy effects derived from the developments made in the project.

Considering also the main impacts generated during the project at this level, the “link” between nanotechnology and thermal systems has shown also a potential contribution to a wider expansion of the nanotechnology to a very huge sector of activity, with a strong ‘local’ character, as is the HVAC sector, which generates a very important quantity of qualified employment with a very high impact over the energy consumption and CO_2 emissions at global level. This effect can generate business opportunities with the proper combination of these specialties, which has shown during the project more connections than those that were planned a priori in the work plan. Wettability and surface treatment, conductivity and mass diffusion of nanotubes of carbon, and corrosion avoidance have been identified and addressed from the nanotechnology approach.

Exploitation of results

During the project execution, seven Exploitation Strategy Seminars and a Final Exploitation Strategy Seminar have been developed, with the aim of consolidating (1) the exploitable results, (2) the claimed background and foreground for each partner (3) the claimed ownership level for each partner, and (4) the planned IPR strategy. In other words, this exploitation strategy brought as the main output the final version of the Plan for Use and Dissemination of Foreground (PUDF).

A list of Exploitable results has been identified by the project partners:

1) A hybrid liquid desiccant based technology for HVAC applications with cooling / heating capability.

- Ideal markets are residential, commercial, manufacturing HVAC applications with high latent / sensible ratios and need of air purity.

- The system is conceived for stand-alone applications.

- Target clients are high level system integrators.

- The technology comprises 3 modules: a polyvalent heat pump unit, the LDS, a specifically adapted Air Handling Unit.

- Other sub-modules comprise:

    - Demister solution
    - Control system + SCADA
    - Monitoring system
    - Liquid-liquid heat exchanger

2) A liquid desiccant based unit for DESICCANT applications.

- The product comprises 2 modules: the LDS, a specifically adapted Air Handling Unit. To operate, the system must be connected to (possibly renewable) sources of hot and cool water. The product does not have cooling capability itself.

- The system is conceived for applications where hot and/or cold sources are already available and only dehumidification is required.

3) Falling film adiabatic heat exchanger for heat and mass transfer comprising:

- A process fiber glass tower (“Tower”)

- A non-atomizing sprinkler (“Distributor”)

- A “Bundle” of plasma treated plastic tubes carrying cooled or heated water

- An advanced ant carryover filtering solution (“Demister”)

Regarding Intellectual Property Right (IPR), the following rules have been established:

- Patenting option has been discarded. There was an interest from one of the partners to patent the plasma treatment of plastic tubes but the prior state-of-the-art search revealed that similar processes have already been invented and, in order to get a patent, the claims would be too narrow.
- The relevant IP, in line with what stated in the Consortium Agreement, must be protected by confidentiality: software, cad drawings, datasets, bill of materials, control algorithms, technical data sheets, installation manuals must not be disseminated outside the consortium unless they are licensed out or sold to an approved Third Party under the authorizations of the co-owners.
- The TBTC prototype in Taipei can be shown to third parties, but in case someone wants to test it, make further R&D, take photos or receive documentation, the IPR committee must be informed.
- The TBTC prototype should remain operational for dissemination purposes at least 24 months (it is built to last for several years though).

The challenge for exploiting commercially the nanoCOOL technology (and therefore to cross the valley of death) is relevant due to the following reasons identified:

- The market analysis performed shows that nanoCOOL market is relatively limited since it must be targeted to high latent / sensible applications, with needs of high air purity that cannot be reached by alternative systems (unless a very strict maintenance is provided).
- Price of nanoCOOL is inevitable driven by its life cycle costs, which are relevant and account approximately double than conventional chilling and heating machines.
- nanoCOOL machine, as all LDAC technologies, is not familiar to the HVAC engineer community, which tends to be rather conservative.
- nanoCOOL has reached all target performances in terms of:
  - Energy efficiency
  - Independent T/H control
  - Low carryover
  - User Comfort

However, nanoCOOL is still in TRL6: this will require additional R&D, which was one of the key discussions made during the final workshop.

<u>Dissemination activities</u>

A Dissemination Plan has been completed, with the objective of identifying and organising the activities performed in order to promote the commercial exploitation of the project’s results and the widest dissemination of knowledge from the nanoCOOL project. The plan is expanded in two directions: towards the marketing activities in order to enhance the commercial potential of the system and towards the notification of project’s results in the scientific, EC and general RTD sector.

Dissemination is a horizontal activity and concentrates on disseminating the results of nanoCOOL project itself to a wide range of existing or potential stakeholders. Special attention has been paid to the transfer of knowledge to Eastern European countries as the Liquid Desiccant Systems (LDS) work effectively under specific conditions – humid and hot climate, which was proven by the system prototype installed and tested in real scale conditions in Taiwan (lockers of a swimming pool). The practical experience and guidance to emerge from the project work have been of relevance to an array of stakeholders within EC and beyond and of value across different sectors and internationally.

The objectives of the dissemination activities within the framework of nanoCOOL project are:

- To provide up-to-date information about the nanoCOOL project.
- To improve the knowledge of nanoCOOL results in the industrial community.
- To share the technical results of the nanoCOOL project with the scientific community.
- To promote the research and receive useful inputs from other scientists and communities.
- To create strong base for future partnerships, collaborations, and information exchange between relevant communities.
- To create European communication channels within industry and scientific communities.
- To attract potential customers.
- To gather feedback from peers, experts, scientists, researchers, potential customers, industry, and the general public.

The main focus for all dissemination activities is on the energy savings, the HVAC systems, the indoor air quality and the building sector in general. Target groups are all players involved in a HVAC system industry, construction and renovation projects:

- Public authorities (local, municipal authorities granting building permits).
- Investors (financial institutions, bankers, project developers).
- Service providers (engineers, construction companies, ESCOs).
- Industry/Manufacturers (HVAC systems' manufacturers/providers, nanotechnology sector, installers).
- Civil society/End-users (building managers, public buildings owners, homeowners, housing associations).
- Standardization/certification bodies (technical chambers, National standard organizations, health institutes focused on indoor quality environment).

Dissemination activities are targeted both nationally and internationally. Tools that are used for dissemination:

- Publications (scientific, technical and economical journals, popular magazines, mailings related to construction, HVAC systems, energy savings).
- Conferences, congresses, workshops, seminars, forums.
- Press releases.

- Fairs, exhibitions.
- Internet (nanoCOOL project website, nanoCOOL workshops website, social network profiles).
- Links to other projects.
- BuildUp portal.
- Leaflets, brochures, roll-up posters, scientific posters.
- Video production (project video, video from the workshop).
- Newsletter, info graphics.
- Stickers for the system prototype.
- Common graphic identity.

Figure 38. nanoCOOL logotype

The public website www.nanocoolproject.eu contains background information and has been up-to-date with results from the project:

- The content is in clear, understandable language.
- The website provides private area (password protected) for the consortium members.
- Coordinator and all partners' information are included.
- Illustrations, designs, photos, videos and downloadable informative poster, brochure are publicly available.
- Information regarding forthcoming events and conferences is included.
- Web address is registered to search engines.
- Social network profiles links and newsletter subscription included

Regarding dissemination material, a four page brochure and one page poster were prepared for the nanoCOOL project in order to increase the awareness of the project.

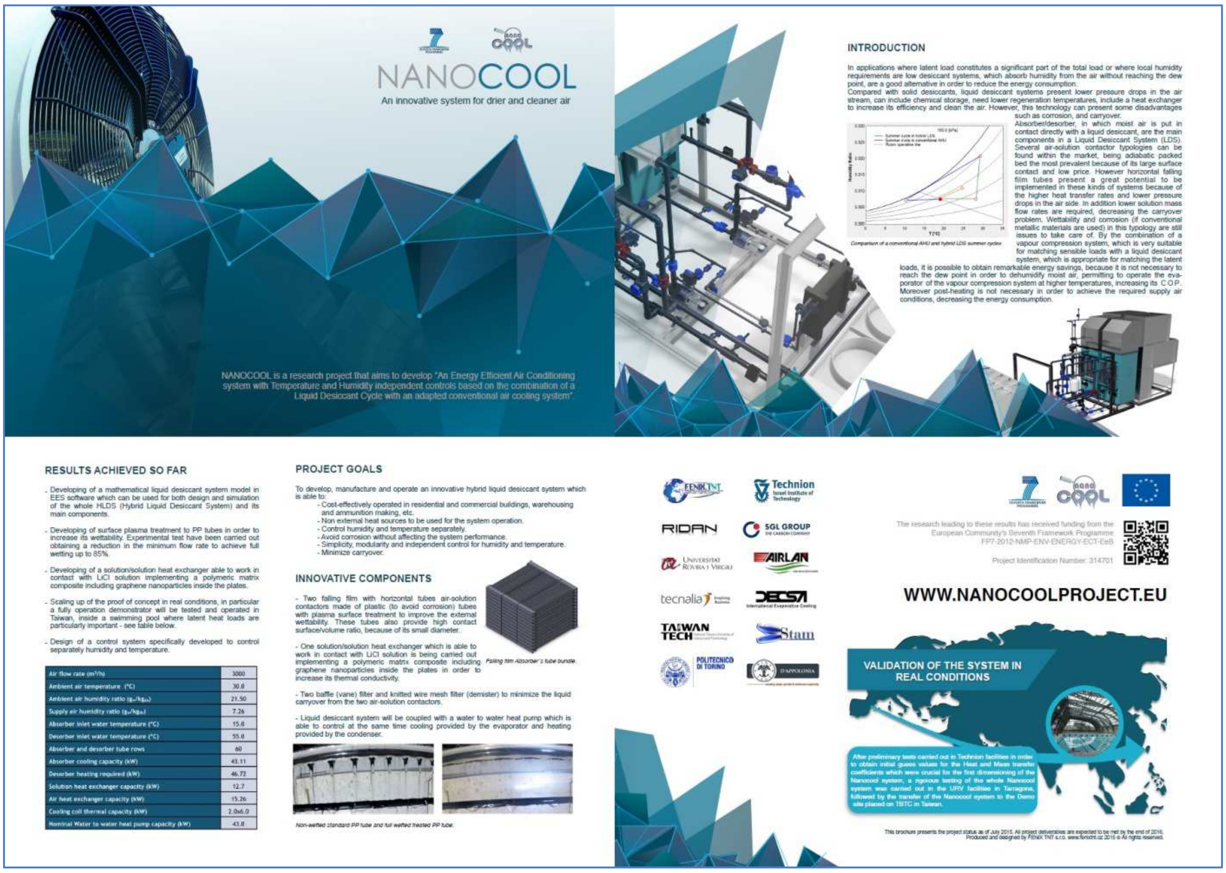


Figure 39. nanoCOOL project brochure

One of the key methods for the effective project dissemination was agreed to be the creation and publication of a project promo video. The video presentation is meant to follow the successive introduction to the strategies regarding the "WWW campaigns": social media promotions, workshops, web advertising in general. Besides the promo video, specific training video following the Installation guidelines for Taiwan demo site, has been created. All videos related to nanoCOOL project can be found on the YouTube channel project profile:

https://www.youtube.com/channel/UCVTqpBKwDQBBLLAbJrEGTfg

In order to raise a public awareness about nanoCOOL project, social network profiles were created – LinkedIn, Google+ page, Twitter and Facebook, YouTube channel - and links were added into nanoCOOL website. The updates and posts have been continuously maintained, based on the partners' contribution (photos from dissemination activities – fairs, conferences, workshops, etc.).

Two important activities for dissemination have been the international workshops organized in the scope of the project.

The first public international workshop for nanoCOOL project was organized on 2nd September 2015 in Prague, Czech Republic; in the premises of Technical Centre ASCR. For the workshop promotion, detailed information and registration online - specific website has been created, and can be accessed on www.nanocoolworkshop.eu.

The event has been promoted in local area (National Contact Point, CzechInvest, Fenix website and social network profiles, ASMP – Association of Small Medium Enterprises, Technical Centre ASCR, BIC Brno – Business Innovation Centre Brno, HVAC companies, technical universities) and in EU area (AMANAC, BuildUp portal, partners websites), as well as information shared on the project website and project social network profiles.

Relevant speakers invited came from Technical university of Liberec, Brno University of Technology, National Contact Point for nanotechnology and advanced materials, ENE-HVAC project, EeB cPPP partnership board, project partners Tecnalia, Technion, D'Appolonia and Fenix.

NANOCOOL WORKSHOP PRAGUE

First Nanocool dissemination workshop has been organized in Technology Centre ASCR, Prague on 2nd September 2015 by project partner FENIX TNT to promote the project and its results to the wide public and to involve stakeholders from HVAC industry, researchers, universities representatives, public bodies and many others to start an open discussion about the innovation and potential which Nanocool system brings to the market.

The workshop visited 36 people, from which 10 were project partners. The whole day session covered all the topics related to the project - energy planning, research and innovation, Liquid Desiccant System technology, exploitation of the project results, cluster approach, thermal exchange challenges, nanotechnology and open discussion between all the participants. Statistics from the workshop are described below as well as the video sumarizing the day.

Thank you all for participation!

Figure 40. Video from workshop Prague (printscreen from the website)

A second public international workshop has been organized at the demo site by National Taiwan University of Science and Technology on 24th February 2016. The website dedicated to the nanoCOOL workshops promotion was updated and the event was shared also on social network profiles, project and workshop website, BuildUp portal, newsletter number 3 and among the partners' contacts.

The workshop in Taiwan included also a webinar for the European attendees who could not come personally at the demo site. Workshop visited about 65 people on-site and by webinar.

This workshop has been a successful event, with the participation of Dr. Jonathan S. Shieh (Taiwan Minister of Science and Technology), and many HVAC related stakeholders, who have shown their interest in the developed technology, and may be interested in promoting the technology in different applications and countries. In the same way, the coordinator has been invited by the Ministry of Economic Affairs to present the project during the European Innovation Week in May 2016.

Figure 41. nanoCOOL International Workshop in Taiwan. Photo gallery