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Assessment of a desiccant cooling system in a traditional and innovative nanofluid HVAC system

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Abstract. The topic of energy saving is a constant in everyday life, and it is widespread all over the world. Space heating using solar panels is the most used renewable source of energy, but the application of solar energy for cooling the fluids used for refrigeration is growing very fast. Among the techniques used for refrigeration, this work focused on Desiccant Cooling. In particular, with the use of dynamic simulation software, it was possible to study the heat supplied and the energy consumption of a Heating Ventilation Air Conditioning (HVAC) system of a university building and to compare consumption with those of a Desiccant Cooling system applied to the same building. Four different cases were simulated: two related to the HVAC system, one of which operates with water and glycol and the other one with nanofluid, and the other ones to the Desiccant Cooling system with both types of fluids mentioned above. Keeping the same energy demand of the building in all the simulations, it was found that in summer the Desiccant Cooling system had higher performance than the traditional HVAC system and that the use of the nanofluid in both types of conditioning systems further increased the performance of 21%. Simulations were carried out using TRNSYS software.

1. Introduction

The summer electrical consumption peaks in Italy, due to both climatic conditions and the huge tourist population are the basic idea of the use of solar energy technologies for air conditioning. Between them, the solar cooling allows the production of cooling energy by solar sources: in summer, the thermal energy from solar radiation can be used to operate thermally activated refrigeration machines, thus reducing peaks in electricity demand, saving primary energy, using renewable energy sources and reducing polluting emissions into the environment. In these systems, solar thermal panels absorb solar radiation to heat a fluid, which provides the process energy to refrigeration machines.

Solar cooling systems can be classified into three categories, as described by Florides *et al.* [1], namely: solar sorption cooling, solar-mechanical systems, and solar-related systems. At the same time, they can be divided into two major families: closed-loop systems and open systems.

Closed systems are realized using “absorption” or “adsorption” refrigeration machines. Both types of machines can produce chilled water at low temperatures from hot water.

Open systems combine dehumidification and evaporative cooling. Between them, one of the oldest techniques is direct evaporative cooling (DEC). This system uses water evaporation to create a cooling effect. Particularly, it is based on a dehumidification process that controls the temperature and humidity of cooling air independently. It consists of a hybrid cooling system, where both sensible and latent loads are handled separately and effectively. Being this process based on the use of heat, it can be coupled with solar collectors to produce an environmentally friendly cooling system. The desiccant wheel is one of the most important components of the DEC: it consists of an electromotor, a wheel disk, and a belt.

The first objective of this work was to calculate the increase in performance of an HVAC system coupled with a desiccant cooling system, operating with a traditional heat transfer fluid or with a nanofluid, as working fluid.

Nanofluids represent a new generation of heat transfer fluids for various applications, because of their good thermal performance. They are dilute suspensions of nanometer-sized particles or fibers dispersed in a liquid [2]. Many researchers have pointed out that the heat transfer performance of nanofluids is better than a pure heat transfer fluid [3],[4]. Sardarabadi *et al.* [5], Zheng *et al.* [6] and Buonomo *et al.* [7] established that the addition of nanoparticles in base fluids improves their heat transfer and absorption characteristics and this good effect depends also on the volume fraction of nanoparticles.

For all these reasons this work focused its attention also on comparing the power consumption of a desiccant cooling system working with traditional heat transfer fluid (water-glycol) and nanofluid. TRNSYS was used to study, analyze and quantify the system efficiency and to evaluate transient and average performance [8]. The last objective of this paper was to compare the economic performance of a desiccant cooling system to a traditional HVAC system.

1.1 Desiccant Cooling system

Evaporative and desiccant cooling technology for air conditioning systems were developed as an alternative to conventional vapor compression systems. Generally, this method combines a dehumidification system based on a desiccant wheel and direct or indirect evaporative systems [9],[10]. Desiccant cooling is a system belonging to the family of solar cooling technology. It is an open cycle that uses a wheel to achieve both cooling and dehumidification.

Absorption dehumidification is the most common type of solar refrigeration system: it is reversible, and regenerative and the physical process results from an interaction between an absorbent and a refrigerant. It is a regenerative process because the desiccant material of the wheel is continuously regenerated, thanks to a heating process based on solar energy. The cooling takes place through continuous evaporation and heat absorption cycles, which occur using a rotating drum, whose external surface is covered by desiccant materials [11]. Currently, the most used absorbents are silica gel (SiO_2), Lithium Chloride (ClLi), Lithium Bromide (LiBr), Activated Alumina (Al_2O_3), and Zeolite.

A fundamental requirement of refrigerant/absorbent mixture is the margin of miscibility, which must be in the range of operating temperature of the cycle. Desiccant systems can use solid or liquid desiccants [12]. The first ones are inexpensive, non-flammable, non-corrosive, and environment-friendly.

The dehumidification and regeneration processes are always simultaneous within the desiccant wheel. Therefore, it is possible to divide the desiccant wheel into two parts: in the first part, the humid air passes through the desiccant wheel for dehumidification, while in the second one, the hot air passes to remove water from the solid desiccant material [13].

A typical scheme of a solar desiccant cooling system is shown in Figure 1.

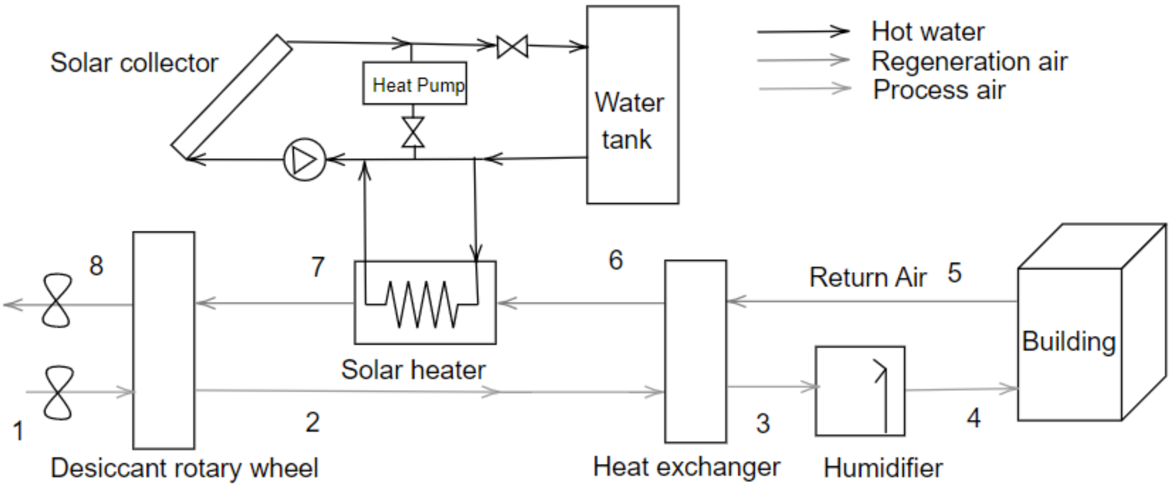

Figure 1.Scheme of a solar solid desiccant cooling system.

In this configuration it is possible to notice that the fresh outdoor air flows through the desiccant rotary wheel (1-2), then is cooled in a heat exchanger (2-3) and a direct evaporative cooler (3-4), providing to the room air in thermal conditions of hygrometric comfort (condition 4). The return air leaves the building and flows through the heat exchanger (5-6), it heats up thanks to the reactivation energy (6-7) and removes the moisture from the adsorbent (7-8).

Galiano *et al.* [14] studied the solar desiccant solid system and its efficiency in a typical Mediterranean Region. Their results confirm that solar energy is an excellent and practical heat source for desiccant regeneration. In addition, they obtained a primary energy saving of around 40% by using a DEC system concerning conventional systems.

Halliday *et al.* [15] studied a desiccant cooling system, based on water and glycol, powered by renewable solar heat. They examined economic feasibility in the UK, finding that, in summer, this system can save up to 39%.

Several experimental and numerical types of research have been conducted to study the operating parameters and the global behavior of desiccant wheels [15],[17]. Many parameters affect desiccant system efficiency and sizing, such as inlet temperature and air humidity, inlet air velocity, typologies, and quantity of drying material [18]. For example, external conditions and external air velocity affect the adsorption of water vapor from the air stream, so low values of inlet air temperature and relative humidity are needed to increase the efficiency of the desiccant wheel.

The greater the amount of desiccant, the more moisture can be removed from the air stream, but more heat and energy are required to regenerate the desiccant material at the end of the process.

The typology of the desiccant material is very important because each material has its properties:

- solids adsorbents retain water on their surface so that the holes of the drying wheel must be not clogged, otherwise their efficiency decreases;
- some materials change their characteristics at high temperatures;
- liquid adsorbents absorb water using chemical reactions, so the presence of other chemical compounds could interfere with the reaction.

Chaudhary *et al.* [19], analyzed the performance of a silica gel-based desiccant wheel dehumidifier and created a thermodynamic model by using various sets of equations for desiccant wheel dehumidifiers. They made a parametric analysis that included various design and climate parameters, according to their effects on the efficiency of the system: for example, the regeneration temperature, which has an effect on the moisture removal capacity or the rotation speed, plays a key role in dehumidification process because a high-speed wheel could produce insufficient time to remove moisture from the air.

1.2 Nanofluids as heat transfer fluids in heating/cooling system

The use of nanoparticles suspended in a base fluid increases the thermal conductivity of heat transfer fluids. Besides, nanoparticles as an additive in heat transfer fluids are preferable to microparticles because they remain in suspension longer and have a specific surface greater than about a factor of 103. Nanofluids are heat transfer fluids with dispersed nanoparticles inside. They have good prospects as an energy-efficient substitute for conventional heat transfer fluids, enhancing the heat transfer performance of refrigeration systems [20]-[22].

Numerical and experimental studies on nanofluids and their applications, confirmed an increase in heat transfer performance of about 10% compared to traditional heat transfer fluids, such as water or water-glycol mixtures, if operating conditions are chosen carefully [23].

Snukrishna *et al.* [24] and Fong *et al.* [25] studied the use of nanofluids in HVAC systems and obtained that their power consumption can be reduced; moreover, the freezing speed and COP can be increased significantly.

Taylor *et al.* [28] investigated the applicability of nanofluids in high flux solar collectors and found an increase in performance of 10% with nanofluids, having a 0.125% volume fraction of graphite. Bozorga *et al.* [29] studied the use of CuO-water nanofluid in automotive diesel engine radiators and their results showed that the nanofluid at 2% volume concentration had a 10% more performance than that of base fluid under the same conditions.

De Risi *et al.* [30] studied the use of a nanofluid as a working fluid in a cooling system for wind turbines; after their studies, they concluded that the use of nanofluids increased the efficiency of the cooling system.

Many researchers have studied the use of nanofluid as a working fluid in solar cooling systems and several studies [31],[32] show that nanofluid can improve the efficiency of solar collectors.

Salem *et al.* [33] and Ande *et al.* [34] studied the behavior of an air conditioning chiller working with water-Al_2O_3 nanofluid and they observed that less time was taken to obtain desired cooling temperature and also that there was a significant improvement in COP.

Colangelo *et al.* [36] and Milanese *et al.* [37],[38] studied the use of nanofluid in solar thermal collectors. In particular, they studied the absorption of solar radiation by transparent solar thermal collectors using nanofluid. Their results showed that nanoparticles of TiO, at a very low concentration, 0.05%vol, were capable of completely absorb solar radiation within 1 cm of depth.

Anwar *et al.* [39] studied nanofluids as heat removal fluid from electronic devices to reach better performance and long technical life. They investigated the thermal performance of CuO water nanofluids in mini-channel heat sinks and obtained a minimum base temperature value that was 9.1% lower than conventional heat transfer fluids. Siddiqui *et al.* [40] compared the CuO nanofluid's performance with Al_2O_3 nanofluid in a flat heat sink and noted that the first one was more effective at a high Reynolds number, but both showed enhancement of about 10% in heat transfer coefficient compared to water.

This work analyzed and compared the energy consumption of a desiccant cooling system based on a traditional heat transfer fluid with the same system working with a nanofluid, which favors the regeneration of silica gel in the desiccant wheel.

2. Numerical model

According to [41]-[43], the building was simulated under transient conditions by using the dynamic software TRNSYS 17. The building (Figure 2), built in 2001, is located in Lecce, Italy (Lat. 40° 19’, Long. 18° 5’). It was simulated as a multizone building by the TRNBUILD module. In particular, it was divided into six different zones, defining orientation, solar gains through the windows, occupancy profile, internal and external gains, etc. Each zone was characterized by an indoor ambient temperature of 26 °C in summer, according to the UNI 10344, and the cooling system was activated from 8:00 am to 4:00 pm.

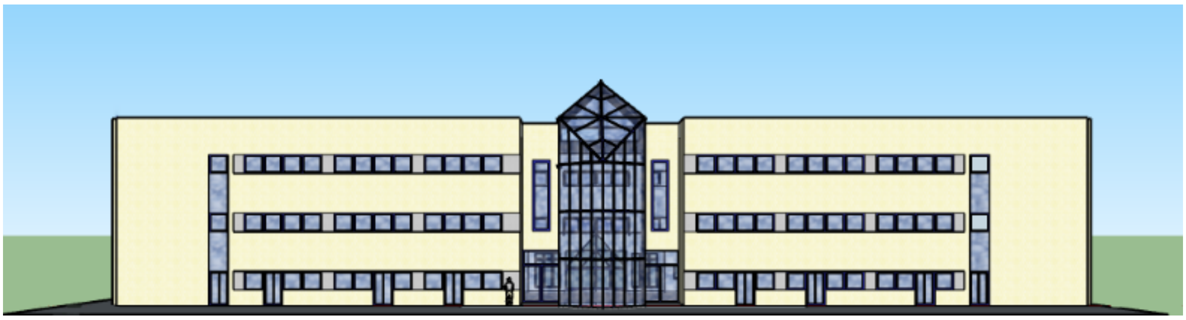

Figure 2. View of the educational building "Corpo O" in the Campus of the University of Salento, Lecce-Italy.

The HVAC system, simulated according to the Italian regulations UNI 10349-1:2016, was based on two heat pumps, whose characteristics are reported in Table 1, and an Air Handling Unit (AHU), that was composed of a crossflow heat recovery unit, a cold battery and a humidifier (Table 2).

Table 1. Heat pumps characteristics.

Template	**WSAN-XEE 302**	
Compressor		
Typology	Scroll	N°2
Refrigerant circuit		N°1
Refrigerant charge	8.28	[l]
Internal exchanger		
Water flowrate	3.4	[l/s]
Maximum water flowrate	5.4	[l/s]
Pressure drop	41.9	[kPa]
Outlet	131	[kPa]
External exchanger		
Fans	N°6	
Standard air flowrate	6971	[l/s]
Power	0.18	[kW]
Expansion case		
Capacity	5	[l]
Maximum pressure on the water	550	[kPa]
Storage tank		
Inertial tank	130	[l]

Table 2. Air Handling Units characteristics.

Template	**Air handling unit UTS 05**	
Air flowrate	6000	[m^3/h]
Useful static pressure	200	[Pa]
Absorbed power	0.55	[kW]
Cold coil with chilled water		
Water flowrate	11.8	[m^3/h]
Air Temperature In	32	[°C]
Air Temperature Out	13.6	[°C]
Pressure drop	169	[Pa]
Flow speed	2.5	[m/s]
Water Temperature In	7	[°C]
Water Temperature Out	12	[°C]
Pressure drop	26.5	[kPa]
Cross flow heat recovery unit with upper shutters		
Supply air flowrate	6000	[m^3/h]
Supply air temperature	-5	[°C]
Extract air flowrate	5000	[m^3/h]
Extract air temperature	22	[°C]
Fresh air temperature	8	[°C]
Total efficiency	49.5	%

2.1 Configuration of the desiccant system

The desiccant wheel and the solar collectors are the most important elements of the desiccant cooling system because the solar collector has the purpose of collecting solar radiation and heating the heat transfer fluid, that will then be used for regeneration of the drying material of the wheel.

In order to transform an existing HVAC system to a desiccant system, the desiccant wheel can be installed within the pre-existing AHU. According to this assumption, Figure 3 compares the current AHU (a) with a theoretical AHU (b), which has been enhanced to match a desiccant system (Figure 3b), by adding a desiccant wheel, an auxiliary heat exchanger for solar collectors, and an evaporative cooler.

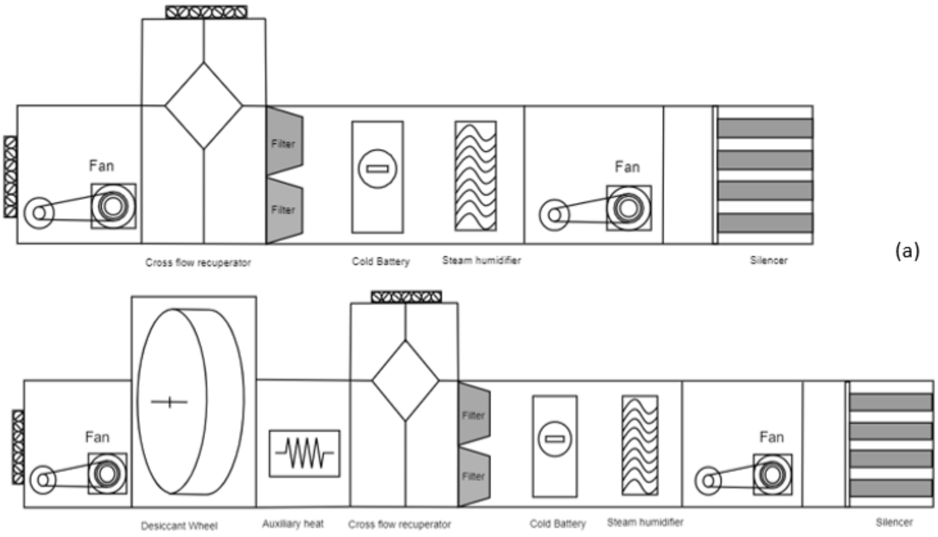

Figure 3. a) Detail of AHU, composed of fans, cross flow recuperator, filters, stream humidifier, and silencer; b) Schematic of the proposed AHU for the desiccant system.

In the case under investigation, the desiccant wheel MDC6000 of DT Group has been chosen, as its parameters are compatible with those of the existing HVAC system (see Figure 4, Table 3, and Table 4).

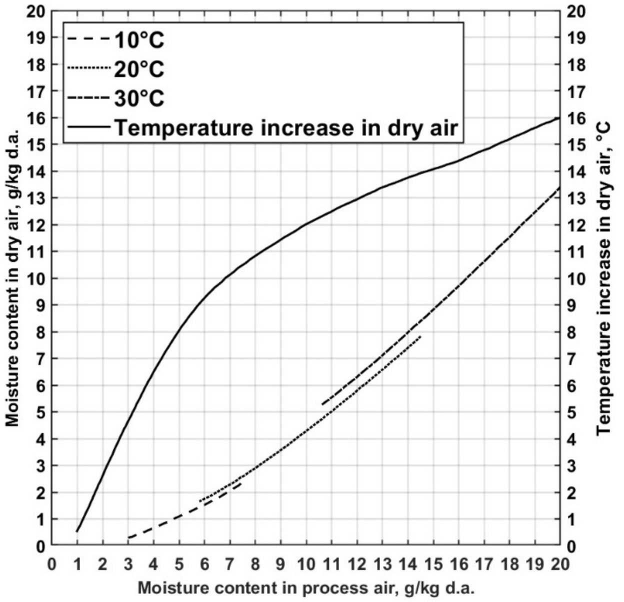

Figure 4. Evaluation diagram of the absorption capacity of the desiccant wheel DMC6000 [44].

Table 3. Approximate capacity in kg/h at different inlet process air relative humidity (%) and temperature (°C) [44].

	Inlet process air relative humidity				
	50%	60%	70%	80%	90%
5°C	17.6	20.2	23.2	25.7	28.2
10°C	23.2	26.9	29.7	32.8	35.4
20°C	35.3	39.4	42.3	44.6	46.4
30°C	43.2	45.7	47.0	48.0	48.2

Table 4. Physical parameters of the desiccant wheel [44].

Process air:	
Rated airflow	6000 [m^3/h]
Available static pressure	400 [Pa]
Reactivation air:	
Rated airflow	17000 [m^3/h]
Available static pressure	320 [Pa]
Power supply:	
(3*400V, 50Hz)	56 [kW]
Current	81 [A]

Taking into account the schematic of Figure 1, the psychrometric chart, shown in Figure 5, illustrates typical cooling/dehumidification processes.

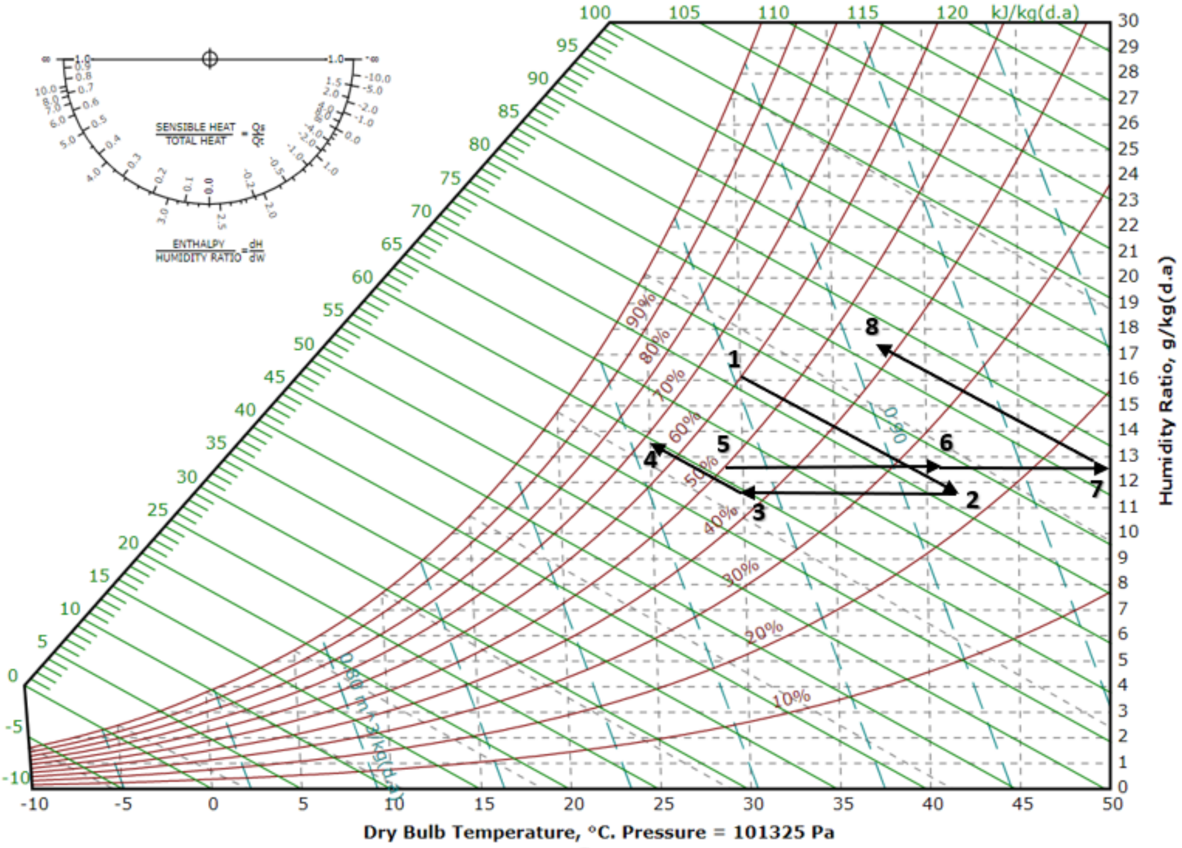

Figure 5. Desiccant system transformations in cooling/dehumidification mode.

The inlet air temperature is supposed equal to 30 °C with a relative humidity of 60%. At these conditions it is possible to observe, that the outlet air temperature to the desiccant wheel reaches the value of 45 °C, according to Equation (1):

$$\dot{m}_{air}(h_2 - h_1) = \dot{m}_{air}(h_7 - h_8) \tag{1}$$

Similarly, the air outlet temperature from the heat exchanger is calculated according to the thermal balance of Equation (2):

$$\dot{m}_{air}(h_3 - h_2) = \dot{m}_{air}(h_6 - h_5) \tag{2}$$

At the exit of the heat exchanger, the air temperature (T_3) is about 30°C, but the inlet temperature in the building (T_4) must be 25°C, therefore the air is chilled using the humidifier. This component uses the principle of air saturation through atomized water to increase the specific humidity, decreasing the temperature. From the psychrometric balance, Equation (3), is obtained the flow rate and temperature of cold water required for humidification: 13.2 m^3/h and 19°C.

$$\dot{m}_{air}x_3 + \dot{m}_v = \dot{m}_{air}x_4 \tag{3}$$

2

At the end of the process, the air temperature is about 25°C.

At point 5, the air exits from the building at 27°C and 50% of humidity; Therefore, it passes through the heat exchanger and the solar heater, reaching at the exhaust the temperature of about 38 °C.

A fundamental part of the system is the heat source that can be used for the regeneration of the drying wheel, which, in this case, consists of solar thermal collectors.

The solar thermal collectors are sized to obtain a temperature of 55°C at the inlet of the desiccant wheel, as required by the data sheet. The collectors must be chosen in such a way that they can produce the needed power and energy to heat the regeneration water and bring it from condition 7 to condition 8

Taking into account the air flow rate of 6000 m^3/h (Table 2) and the temperature at the exit of the heat exchanger of 38 °C, the temperature variation of the air between the heat exchanger and desiccant wheel is 13°C, so the solar collector's power can be calculated by Equation (4), finding a value of 22 kW:

$$P = \dot{m}_{air} \Delta h_{7-8} \tag{4}$$

2.2 TRNSYS model

According to the schematic of Figure 1, the system was modelled in TRNSYS, as shown in Figure 6, where:

- Type 683 represents the desiccant wheel;
- Type 659 represents the solar heater;
- Type 91 represents the heat exchanger;
- Type 506 represents evaporative cooler;
- Type 56a represents the building;
- Type 505 represents the heat pumps;
- Type 538 represents the solar thermal collector heats;
- Type 4a represents the storage heat system from the solar thermal collectors;
- Type 744 represents the fan;
- Type 3 represents the circulation pump;
- Type 15 represents the weather;

Type 515 represents the heating and cooling season scheduler.

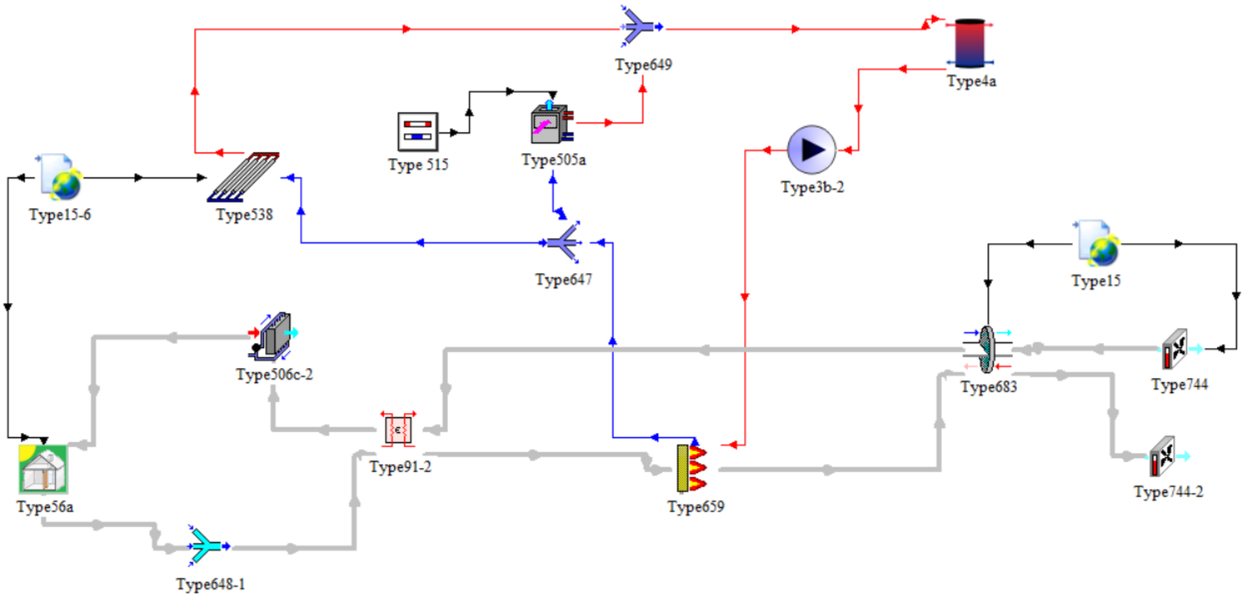

Figure 6. Desiccant cooling system model in TRNSYS.

The model has two main circuits: the first one is related to air (grey lines), while the second one regards the heat transfer fluid (red and blue lines). In the air circuit, the air is taken from the environment using a fan (type 744) and passes through a desiccant rotary wheel containing silica gel (type 683), a heat exchanger (type 91-2), an evaporative cooler (Type 506), reaches the building (Type 56a). Therefore, the air, exiting from the building returns to the rotary wheel, to regenerate the desiccant material. After this step, the exhaust air is expelled outside by a fan (type 744-2).

In the heat transfer fluid circuit, the solar thermal collector (Type 538 - this component has the option of specifying a variable speed pumping control strategy to keep the outlet temperature at a user-specified value; the solar collector array consists of collectors connected in series and parallel; the thermal performance is determined by the number of modules in series and the characteristics of each module) heats the fluid, which is stored in a tank (Type 4a). From here, the heat transfer fluid reaches the solar heater (Type 659), where transfers heat to the air and returns to the solar collector through the circulation pump (Type 3b). The model used a time step of 1 hour.

Type 56a models the thermal behavior of the building, whose characteristics have been obtained in [2] by running the pre-processor program TRNBuild. Particularly, the required thermal loads are reported in Figure 7.

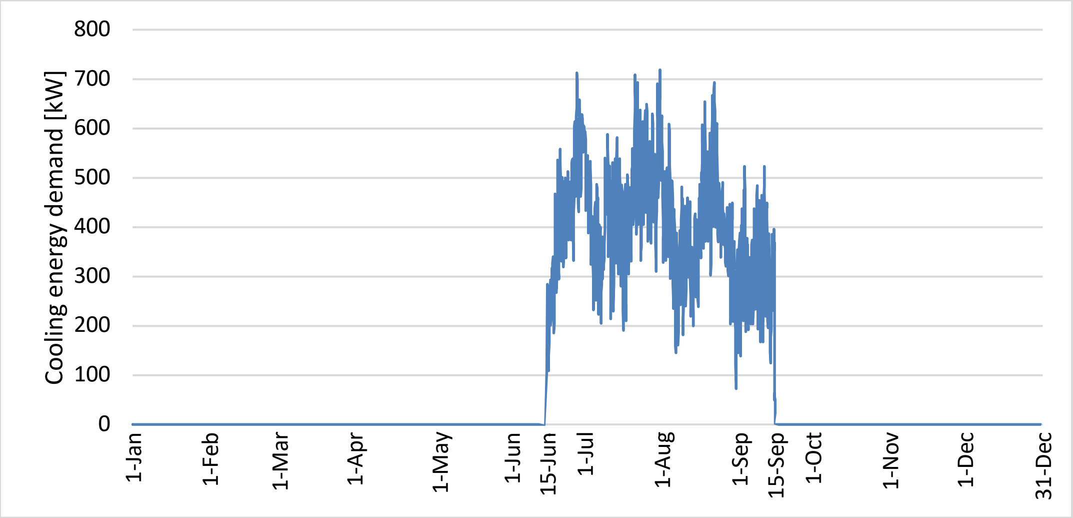

Figure 7. Energy demand for “Corpo O” by dynamic simulation [2].

Table 5 summarizes the parameters that have been used in the model of the building. All simulations have been carried out according to the following occupancy profile: 8.00 am - 6.00 pm from Monday to Friday for teachers, school staff, and students, while for teachers and school staff 8.00 am - 2.00 pm Saturday too.

Table 5. Parameters and internal gains used in TRNBuild for building modeling.

Parameter	Value	Reference
Occupancy	Occupancy Profile	ISO 7730
Indoor ambient temperature	20°C in winter 26°C in summer	UNI 10344
Humidity	50%	UNI 10344
Infiltration	0.5 change/h	UNI 12831-2006
Ventilation	1 change/h	UNI 12831-2006
Internal gains convective power	Printer 360 kJ/h Server 3607 kJ/h Copy machine 200 kJ/h	ISO 52016-1:2017
Artificial Lighting	17 W/m^2	
Comfort type	Clothing factor 1 Metabolic rate 1.2 Relative air velocity 0.1	

The typical meteorological year, representing the climate of Lecce, included within TRNSYS weather data files (Type 15), was employed as climatic input data.

3. Simulation results and discussion

Several dynamic simulations were carried out in order to evaluate and compare performance and energy consumption of the plant under investigation, working with nanofluid and traditional heat transfer fluid (water/glycol).

Figure 8 shows a comparison between the numerical results related to 4 different simulations:

1) HVAC system working with water glycol as heat transfer fluid;
2) HVAC system working with nanofluid as heat transfer fluid.
3) HVAC system coupled with desiccant system working with water glycol as heat transfer fluid;
4) HVAC system coupled with desiccant system working with nanofluid as heat transfer fluid.

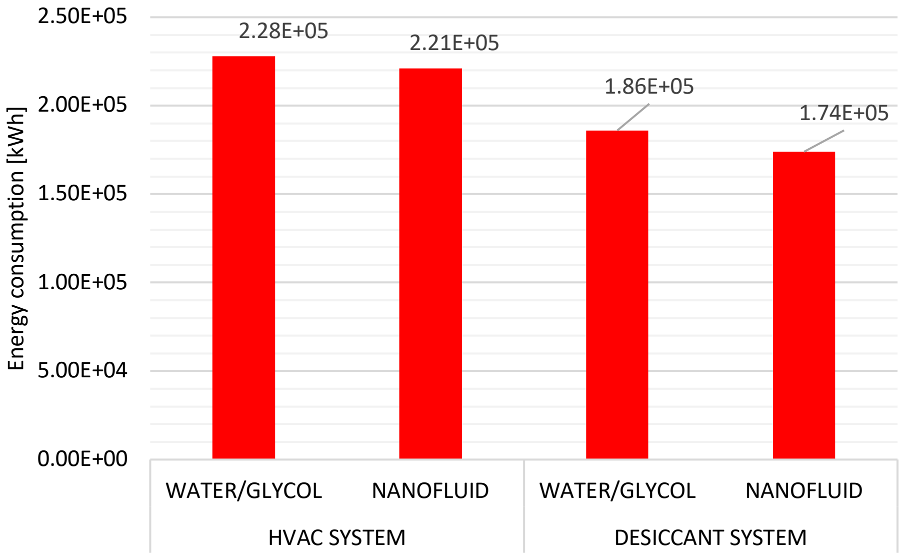

Figure 8. Heat pumps electric energy demand.

It is possible to notice the high energy saving (up to 18%) obtained with the desiccant cooling system compared to the standard HVAC system. This saving is strictly related to the desiccant wheel, which is regenerated by the solar heat, allowing to reduce the heat pumps work, with respect to the traditional HVAC system. Besides, the use of a nanofluid as heat transfer fluid allows further advantages (3% more energy savings), that are justified by the fact that the nanofluid is an excellent heat transfer fluid, alternative to the traditional water/glycol, because of its higher heat transfer coefficient.

4. Economic evaluation

According to Jani *et al.* [45], solar powered desiccant cooling is economically convenient. In this work, the energy consumption of a desiccant-cooling system operating with traditional heat transfer fluid and nanofluid has been analyzed and compared. In summer, the system uses mainly the heat generated by the solar field to regenerate the drying material of the wheel. Therefore, the air through appropriate elements, such as the heat exchanger and the humidifier, reaches the design conditions related to the indoor environment.

To realize an economic evaluation of the solar-powered desiccant cooling system and to economically compare its performance with the current HVAC system, it is important to remark that some elements, such as heat pump, fans for air extraction, hot/cold batteries and humidifier, are in common between the two systems, but, in addition, there are other components, such as the drying wheel and the solar thermal system, that increases the cost of the desiccant cooling plant, reducing the electrical power consumption because of the solar energy.

The purchase costs of the new elements, needed to transform the HVAC system into the desiccant cooling system, are reported below:

- thermal solar system: it has a price that depends on the number of panels and their surface; in the case under investigation 20 m^2 is needed to supply the desiccant cooling system having a total cost of 17360 €. The total collector's surface is calculated by a program called SOLAR-T 2.0 and the price is 800 €/m^2 according to the price list of Apulia region [47].
- drying wheel: for large systems, as in the case under investigation, the cost can be considered equal to 7.5 €/(m^3/h); therefore, for a flow rate of 6000 m^3/h, the total cost is 43860 €.

Therefore, the total extra costs incurred for the purchase and installation of the desiccant system are equal to 61220 €.

The purchase and installation costs of solar panels can be repaid with a significant reduction in energetic costs, against a minimum increase for maintenance. Indeed, taking into account the electric energy consumption of Figure 8 and considering an electricity cost equal to 0.30 €/kWh [48], it was calculated the operating costs for both systems (Table 6).

Table 6. Electricity costs per both systems.

System	Energy consumption	Costs
HVAC System with water and glycol	2.28E+05 [kWh]	68400€
HVAC System with nanofluid	2.21E+05 [kWh]	66300€
DEC System with water ang glycol	1.86E+05 [kWh]	55800€
DEC System with nanofluid	1.74E+05 [kWh]	52200€

Comparing the electricity cost of the HVAC system with the desiccant cooling system working with nanofluid, it was possible to calculate an annual saving equal to 15200 €

The maintenance costs can be divided into:

- general maintenance cost of the air conditioning system: it is provided both for a traditional air conditioning or heating system and for a desiccant cooling system. The cost of ordinary maintenance of hydrothermal, sanitary and air conditioning systems is about 10000 €/year, according with the Puglia region price list [47].
- maintenance of the desiccant wheel: the filters of the drying wheel and the rotating heat exchanger should be changed every two months, while all the other elements of the drying wheel have a longer lifespan, about five years. The drying material, the silica gel, does not require continuous maintenance, but only replacement after about 100000 hours of operation, therefore, in general, desiccant components do not require much maintenance. Therefore, the maintenance cost can be estimated equal to 1000 €/year [47] if the system works from 8.00 a.m. to 4.00 p.m., from June 15^{th} to September 30^{th}, as in the case under investigation.

The economic convenience of the investment has been evaluated through the Pay Back Period, according to Equation (5):

$$SPB = SC/R \tag{5}$$

with SC extra costs of the alternative solution compared to the traditional one and R annual saving achieved with the alternative solution. Particularly, considering the installation cost and the annual saving related to the desiccant cooling system working with a nanofluid, the payback period of the investment is equal to 4 years.

5. Conclusion

This study evaluates and compares the HVAC system performance with a DEC system working with water/ glycol and nanofluid. As expected, the system using a nanofluid as heat transfer fluid was more efficient and had a lower consumption than the conventional system for the same amount of heat supplied. In addition, the proposed desiccant cooling technology was cost-effective due to lower electricity consumption for cooling.

From a first analysis of consumptions, it is highlighted that, in summer, the current system has a higher consumption of electricity than the solar cooling one and this is closely linked to the use of the heat pump. In other words, desiccant systems reduce the cooling load on the conventional system. Indeed, the use of the desiccant system with traditional heat transfer fluid produces a saving of about 18% compared to the current refrigeration system operating with a heat pump.

Other simulations were carried out with a drying wheel, and with the use of nanofluid instead of water/glycol, the energy savings were up to 21%.

The economic evaluation study has obtained a result of return-on-investment time of about 10 years.

All these data confirm the feasibility of the desiccant cooling system with the use of a nanofluid as a heat transfer fluid, thus obtaining greater energy savings with the same energy demand of the building.

6. Nomenclature

AHU	Air Handling Unit
$\dot{C}_c$	Thermal flow capacities about the time unit of the cold fluid [$\mathrm{JK^{-1}s^{-1}}$]
$\dot{C}_h$	Thermal flow capacities in relation to the time unit of the hot fluid [$\mathrm{JK^{-1}s^{-1}}$]
c_p	Specific heat [$\mathrm{Jkg^{-1}K^{-1}}$]
COP	Coefficient of Performance
DEC	Desiccant Cooling
h	specific enthalpy [J/kg]
HVAC	Heating Ventilation Air Conditioning
IEC	Indirect evaporate cooling
m_v	vapour mass flow rate [$\mathrm{kgs^{-1}}$]
P	Solar collector power [kW]
$\dot{Q}$	Thermal power [$\mathrm{Js^{-1}}$]
R	Annual savings achieved [€]
SC	Extra cost [€]
SPB	Pay Back Period
T_c	Cold air temperature [K]
T_h	Hot air temperature [K]
T_{reg}	Regeneration temperature at inlet [K]
x	specific humidity ratio [$\mathrm{gvkgair^{-1}}$]

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