EXPERIMENTAL INVESTIGATION AND SIMULATION STUDY ON A DESICCANT AIR-CONDITIONING SYSTEM IN BRAZIL

Jesus Marlinaldo de Medeiros, jesus_medeiros@yahoo.com.br
Federal Institute of Education, Science and Tecnhnology of Pernambuco, PE-60, Km 14, Ipojuca, Pernambuco, Brazil

Marcio Gomes da Silva, mgcefet@gmail.com
Federal Institute of Education, Science and Tecnhnology of Paraíba, João Pessoa, Paraíba, Brazil

Jailson charles dos Santos, jsurca@yahoo.com.br
Material and Metallurgical Engineering Department, Regional University of Cariri, Crato, Ceará, Brazil

José Maurício Gurgel, jm.gurgel@uol.com.br
Mechanical Technological Department, Federal University of Paraíba, João Pessoa, Paraíba, Brazil

Abstract. This work presents results of experimental and simulation study of a desiccant air-conditioning system in Brazi, operating in opened cycle, which is composed of desiccant wheel, sensible wheel, evaporative coolers, and heater for regeneration of the desiccant wheel. The desiccant air-conditioning system reduces the energy consumption, improve the quality of interior air, increase the thermal comfort and do not attack the environment. An experimental setup was designed and built to evalute the performance system under various operation conditions. The results are presented in terms of temperature and absolute humidity profiles of the each equipmant what it will impact in the perfomance of the system. In this initial phase of the project, coherence in the gotten results with data supplied for the manufacturer of the used equipament can be evidenced. However, some problems due the located emptying had provoked discrepancies in the waited results. Also it will be possible to corroborate in the simulation, mathematical modeling and analysis of results of the complete system through a computational code that supplies a dynamic reply. The computational code allows diminishing the amount of experiences to be carried through in the laboratory and to determine its economic viability for the studied region. The dynamic reply of the complete system was observed imposing the real conditions of the installation without prescribing the condition of ideal comfort. The mathematical model has been validated by comparing with experimental data and numerical results. The coefficient operational of performance (COP) of the simulated system adjust the available numerical and experimental data. It is observed that a desiccant system the two wheels do not provide thermal comfort for tested region, being necessary a configuration with three or four wheels.
Keywords: Air conditioning, Desiccant system, Dehumidification, Evaporative cooler, Experimental

1. INTRODUCTION

For global sustainable development, it is necessary to reduce the primary energy consumption and to introduce renewable energy. The reduction of the primary energy can be performed with a reasonable utilization of waste thermal energy in a refrigeration process. Most of the refrigeration and the heat pump technologies are dominated by vapor compressor systems. The vapor compressor system, however, is highly concerned with the environmental regulations.

Refrigeration and air conditioning system influences the environment in three aspects. Firstly, the CFCs and HCFCs used as working fluids are ozone-depleting substances. Secondly, refrigerant such as CFCs has the global warming potential. Recent natural disasters around the world have shown the negative effects of greenhouse gases including various refrigerants. Thirdly, refrigeration system consumes energy which in general is produced from fossil fuel and related to release of pollutions. These pollution materials, such as CO, SO_x and NO_x are harmful to the health of people, Wang and Liu, (2007). Particularly, air e water are clean, no combustibility and relatively low-pressure gas that is extremely safe natural refrigerants.

Conventional vapor-compression-based cooling systems are not able to cope with the current humidity standards required by the production and the storage of humidity sensitive products. Currently, the interior air quality (IAQ) rigid standards made problematical the use of conventional air conditioning system, especially in extreme humidity conditions. Presently, the best technical solution for the control of humidity, temperature and flow rate of the process air is given by desiccant air-conditioning systems, which are largely spread among the industrial processes.

Desiccant systems has several advantages relative to their closed-cycle counterparts: they operate at ambient pressure; heat and mass transfer between the air and the desiccant take place in a direct contact; both cooling and dehumidification of the conditioned air may be provided, in variable quantities, to fit the load in the conditioned space. Disadvantages are the low COP, due to inherently inefficient regeneration; relatively large air volumes must be pumped, leading to potentially high parasitic losses; contamination of the desiccant by dirt and dust contained in the air my require its replacement after some period of operation.

Desiccant technology is now being applied in buildings and space where humidity levels are critical such as supermarket frozen and cold food areas, hospital operating theatres, nursing homes, schools, hotels, convention centers and theatres. The technology is also applicable to buildings requiring a high fresh air intake in humid climate zones.

The major advantage of desiccant cooling is a significant potential for energy savings and reduced consumption of fossil fuels. The electrical energy requirement can be very low compared with conventional refrigeration systems. The source of thermal energy can be diverse (for instance, solar, waste heat, natural gas, among them).

Desiccant cooling systems work based on the principles of desiccant dehumidification and evaporative cooling. A desiccant dehumidification system is a device, which contains an adsorbent to adsorb and desorb moisture in process air and regeneration air, respectively. The core component of the dehumidification system is a rotary heat and moisture exchanger, which can be classified into enthalpy (or energy) wheel and desiccant wheel based on its function, operation condition and the wheel's configuration.

The desiccant wheels, basically consist of a rotary matrix composed of numerous corrugated channels, through which two process streams flow (usually in a counterflow arrangement), continuously exchanging heat and moisture. The geometries of these channels closely resemble sinusoidal functions. Although desiccant and enthalpy wheels are very similar devices, there is a fundamental difference on the proportions of heat and mass they are designed to transfer: in desiccant wheels the main emphasis is the mass transfer, whereas enthalpy wheels are designed to transfer comparable fractions of heat and mass.

The desiccant wheel rotates slowly to expose one portion of the desiccant material to the process air stream while the other portion simultaneously passes through the regeneration air stream. A partition and flexible seal separates the process and regeneration air in the desiccant wheel. Moist air enters the process side and passes ones the desiccant and is dehumidified. Regeneration occurs on the other side of the partition where heated air enters most often from the opposite direction, them passes over the desiccant, and finally laden with moisture is exhausted from the desiccant wheel.

The enthalpy wheel rotates between the outside fresh air (process air) and the exhaust air from room. Heat and humidity would be recovered from the exhaust in the winter and excess heat and moisture would be transferred to the exhaust to cool and dehumidify the process air in the summer.

The performance of the desiccant wheel depends on several parameters, like as ambient air condition (temperature and humidity), regeneration air, volumetric flow rates and rotation. Other wheel specific parameters are geometry structure and sorption properties of the material.

The desiccant technology has being studied and implemented in diverse countries being distinguished the United States, China, India, Japan, Australia, Canada, and more recently Brazil. Pertinent literature to the desiccant wheels can well be evaluated, Ge *et al.* (2008). Specifically, in Brazil the works using the desiccant technology are involved with adsorption refrigeration and desiccant air conditioning systems (Gurgel, 1994; Camargo and Ebinuma, 2005; Nóbrega and Brum, 2006; Medeiros *et al.*, 2007).

In the present work, the main objective is to develop a computational code for simulation and evaluation of the performance of a desiccant air-conditioning system with two wheels in an enclosure to be climatized to be used in the northeast region of Brazil, maximizing the performance, minimizing the costs and corroborating in the construction of an experimental archetype.

2. DESICCANT EVAPORATIVE COOLING SYSTEM

A typical desiccant cycle can be cost effective when removing humidity from the air. However, regeneration of the desiccant requires heating roughly equal to the energy it provides for dehumidification. When using evaporative final cooling, the system can deliver a range of warm dry air or cool humid air at relatively high COP.

A typical two wheel desiccant cycle is shown in Fig. 1 and the corresponding states of the air in the cycle are shown in Fig. 2. The air follows the following processes during the system: 1 - 2 sorptive dehumidification of supply air; the air is heated by the adsorption heat and the hot matrix of the wheel coming from the regeneration side; 2 - 3 sensible wheel pre-cooling of the supply air in counter-flow to the return air from the building; 3 - 4 evaporative cooling of the supply air to the desired supply air humidity by means of a humidifier; 4 - 5 supply air temperature and humidity are increased by means of internal loads; 5 - 6 return air from the building is cooled using evaporative cooling close to the saturation line; 6 - 7 the return air is pre-heated in counter-flow to the supply air by means of a high efficient air-to-air sensible wheel; 7 - 8 regeneration heat is provided for instance by means of a heater; 8 - 9 the water bound in the pores of the desiccant material of the dehumidifier wheel is desorbed by the hot air, exhaust air is blown to the environment by means of the return air fan.

Obviously, the global thermal behaviour of such a system depends on all particular processes that occur in the air conditioning unit. However, the behaviour of the desiccant medium is a crucial issue that needs a specific treatment, based on a dynamic analysis of the simultaneous heat and mass transfer.
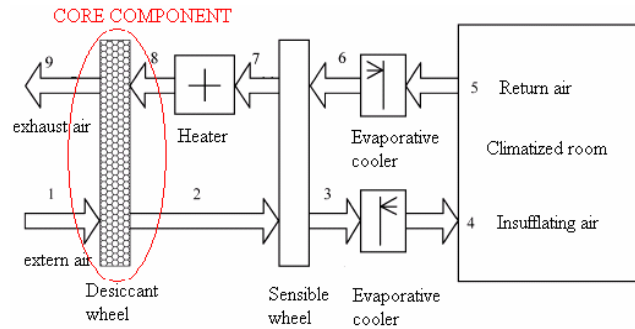
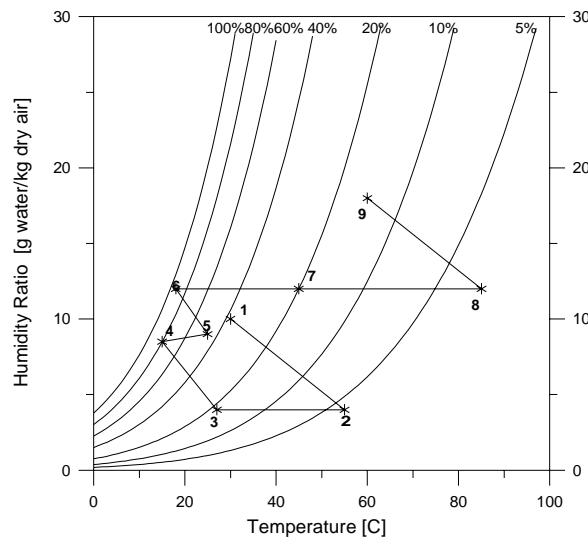Figure 1. Desiccant evaporative cooling system

Figure 2. Psychrometric chart representation of desiccant system

3. PERFORMANCE OF THE DESICCANT EVAPORATIVE COOLING SYSTEM

The usual procedure for determination of the performance of any desiccant system is exactly individually to simulate each component, one by one, until the condition of periodic regime. Another adopted procedure is to simulate of transient form the desiccant rotor and to apply effectiveness prescribed in the excessively component ones.

The numerical validation will be compared with numerical results gotten by Ruivo *et al.* (2004), remembering that the mathematical model of the desiccant wheel is different of the used one in this work and that the excessively component ones had been applied prescribed effectiveness. And will be tested two configurations here: one with prescribed effectiveness and another one without prescribed effectiveness.

The experimental validation will be compared with experimental data in permanent regime gotten by Jin et al. (1998), for in such a way, the effectiveness prescribed through the values of temperature and humidity in the entrance had been determined and exit of each component. Testing the two configurations cited previously.

3.1. Numerical validation

The cooling desiccant evaporative system studied in the sub-section is a constant air-volume installation, where supply air is 100 % exterior air, opened cycle, (Ruivo *et al.,* 2004).

The room thermal loads are mainly of sensible heat. To simplify the present analysis, the sensible load is supposed to have a constant component, which takes into account the internal sources and the solar radiation.

The following list of input data values was considered:

Initial air state in the system: Temperature 30 ºC and Moisture content: 10 g water / kg dry air

Outdoor air: Temperature 30 ºC and Air moisture content: 10 g water / kg dry air

Sensible room load: 10.1 kW   Latent room load: negligible   Airflow rate: 2.4 kg/s (7200 m³/h)

Heat recovery exchanger efficiency: 0.75   Evaporative coolers efficiency: 0.9
Heating coil: 97 kW

Desiccant wheel: In the formularization of the problem of heat and mass transfer in desiccant wheel a model of instantaneous balance was used, (Simonson, 1998). The parameters of the wheel and the properties of the desiccant matrix are detailed here: The involved constants in the adsorption isotherm are C=1, f=0.75, kg water / kg desiccant Wmax=0.4. The properties of the matrix (desiccant + substratum) are ρ_d=234.2 kg/m3, Cp_d=1300 J/kg K, m_d=119.0 kg of desiccant, Cp_{al}=903 J (kg K), ρ_{al}=2702 kg/m3, k_{al}=237 w (m K), σ_d=0.77 (fraction of desiccant in the matrix). The used desiccant material was to the silica gel. The used geometric dimensions in the wheel had been: L=0.2 m and D=1.9 m (diameter of the wheel), t_d=0.1 mm (thickness of the desiccant one), t_{al}=0.03 mm (thickness of substratum-aluminum), Dh=1.47 mm (hydraulical diameter). The geometry of the canals in the wheel was approached by the sine curve formed for a base of 3.62 mm and a height of 1.81 mm. The speed rotation 20 rph, what it results in 180s a complete cycle to each cycle of adsorption and desorption of 90 s, respectively.

The operational coefficient of performance (COP) for the desiccant system with two wheels can be express for the following equation:

$$COP = \frac{\dot{Q}_{refrig}}{\dot{Q}_{regen}} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_8 - h_7)}$$ [1]

Where $\dot{Q}_{refrig}$ represents the cooling capacity of the desiccant system in kW and $\dot{Q}_{regen}$ is the thermal energy used to regenerate the desiccant wheel, in kW; $\dot{m}$ is the air flow that passes in each equipment of the system and h is the enthalpy specifies of air in definitive point of the system.

The calculation of the COP for both the systems in analysis is shown in Tab. 1.

In Table 1, it is observed that the value of the COP is inferior to the found one for Ruivo *et al.* (2004), and that the model without effectiveness prescribed in the sensible wheel better adjusts that the model with prescribed effectiveness. These discrepancies can be fruits, of the uncertainties of used variable or information supplied in Ruivo *et al.* (2004).

Table 1. Performance of the desiccant system, Ruivo *et al.* (2004).

	Ruivo *et al.* (2004)	Present work with prescribed effectiveness	Present work without prescribed effectiveness
COP	0.48	0.36	0.45

In Figure 3, it is shown to a psychrometric representation of the desiccant system with the information of temperature and absolute humidity in each point that facilitates the analysis of the results gotten for each employed model. It is observed that the model without prescribed effectiveness better adjusts that to the other model.
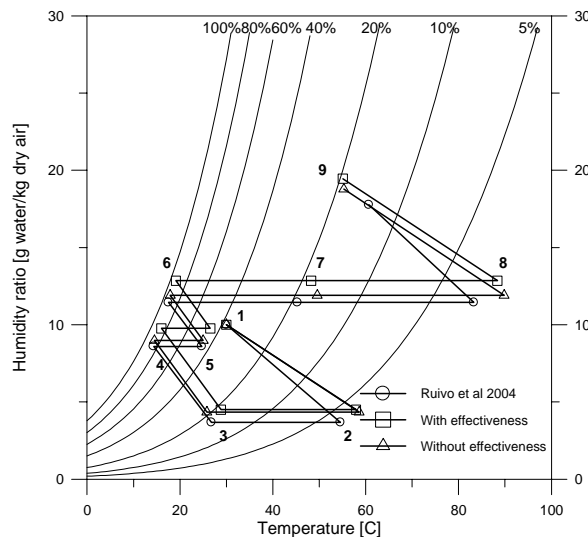

Figure 3. Psychrometric chart representation of desiccant system, Ruivo *et al.* 2004

Figure 4 show the values of temperature and humidity ratio, respectively, of the airflows at specific points of the desiccant cooling system from the initial to the final stationary conditions. For this case, the results obtained show that the stationary regime is achieved approximately in 1440 seconds.
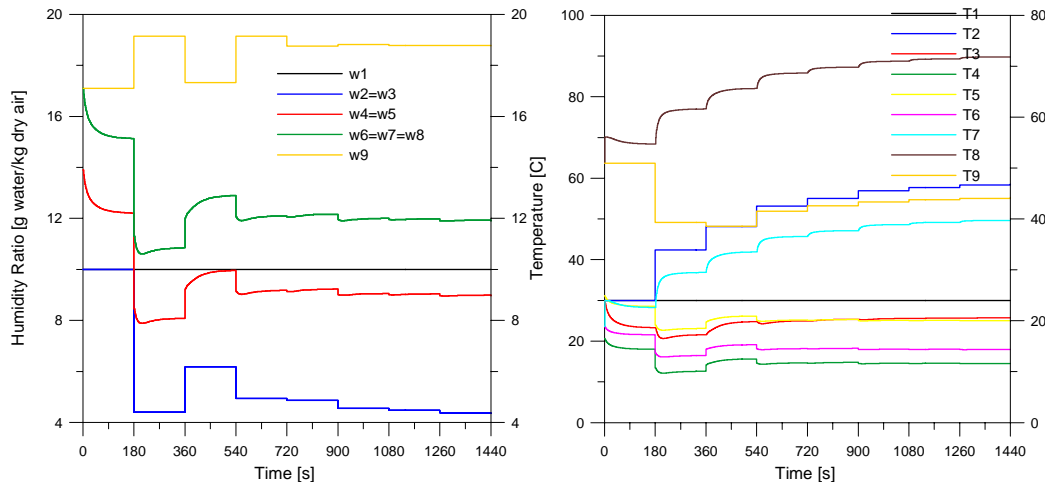

Figure 4. Evolutions of the air conditions: temperature and humidity ratio, Ruivo *et al.* 2004

3.2. Experimental validation

The cooling desiccant evaporative system studied in the sub-section is a constant air-volume installation, where supply air is 100 % exterior air. Opened cycle, (Jin *et al.* 1998).

The room thermal loads are mainly of sensible heat. To simplify the present analysis, the sensible load is supposed to have a constant component, which takes into account the internal sources and the solar radiation.

The following list of input data values was considered:

Initial air state in the system: Temperature 35.4 ºC and Moisture content: 13.74 g water / kg dry air

Outdoor air: Temperature 35.4 ºC and Air moisture content: 13.74 g water / kg dry air

Sensible room load: 10 kW   Latent room load: negligible   Airflow rate: 2/3 kg/s (2000 m^3/h)

Heat recovery exchanger efficiency: 0.84   Evaporative coolers efficiency: 0.9

Heating coil: 18 kW

Desiccant wheel: In the formularization of the problem of heat and mass transfer in desiccant wheel a model of instantaneous balance was used, (Simonson, 1998). The parameters of the wheel and the properties of the desiccant matrix are detailed here: The involved constants in the adsorption isotherm are C=1, f=0.75, kg water / kg desiccant Wmax=0.4. The properties of the matrix (desiccant + substratum) are ρ_d=250 kg/m3, Cp_d=600 J/kg K, m_d=70.0 kg of desiccant, Cp_{al}=903 J (kg K), ρ_{al}=2702 kg/m3, k_{al}=237 w (m K), σ_d=0,77 (fraction of desiccant in the matrix). The used desiccant material was to the silica gel. The used geometric dimensions in the wheel had been: L=0.2 m and D=1.22 m (diameter of the wheel), t_d=0.2 mm (thickness of the desiccant one), t_{al}=0.05 mm (thickness of substratum-aluminum), Dh=1.47 mm (hydraulical diameter). The geometry of the canals in the wheel was approached by the sine curve formed for a base of 3.62 mm and a height of 1.81 mm. The speed rotation 10 rph, what it results in 360 s a complete cycle to each cycle of adsorption and desorption of 180 s, respectively.

The calculation of the COP for both the systems in analysis is shown in Tab. 2.

In Table 2, it is observed that the value of the COP is inferior to the found one for Jin *et al.* (1998), and that the model with effectiveness prescribed in the sensible wheel better adjusts that the model without prescribed effectiveness. These discrepancies can be fruits, of the uncertainties of used variable or information supplied in Jin *et al.* (1998).

Table 2. Performance of the desiccant system, Jin *et al.* (1998).

	Jin *et al.* (1998)	Present work with prescribed effectiveness	Present work without prescribed effectiveness
COP	0.85	0.74	0.48

In Figure 5, it is shown to a psychrometric representation of the desiccant system with the information of temperature and absolute humidity in each point that facilitates the analysis of the results gotten for each employed model. It is observed that the model with prescribed effectiveness better adjusts that to the other model.
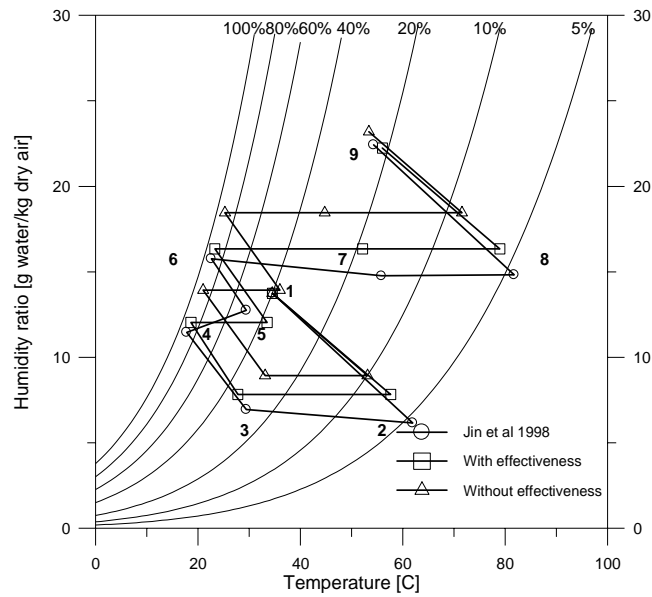

Figure 5. Psychrometric chart representation of desiccant system, Jin *et al.* 1998

Figure 6 show the values of temperature and humidity ratio, respectively, of the airflows at specific points of the desiccant cooling system from the initial to the final stationary conditions. For this case, the results obtained show that the stationary regime is achieved approximately in 3960 seconds.
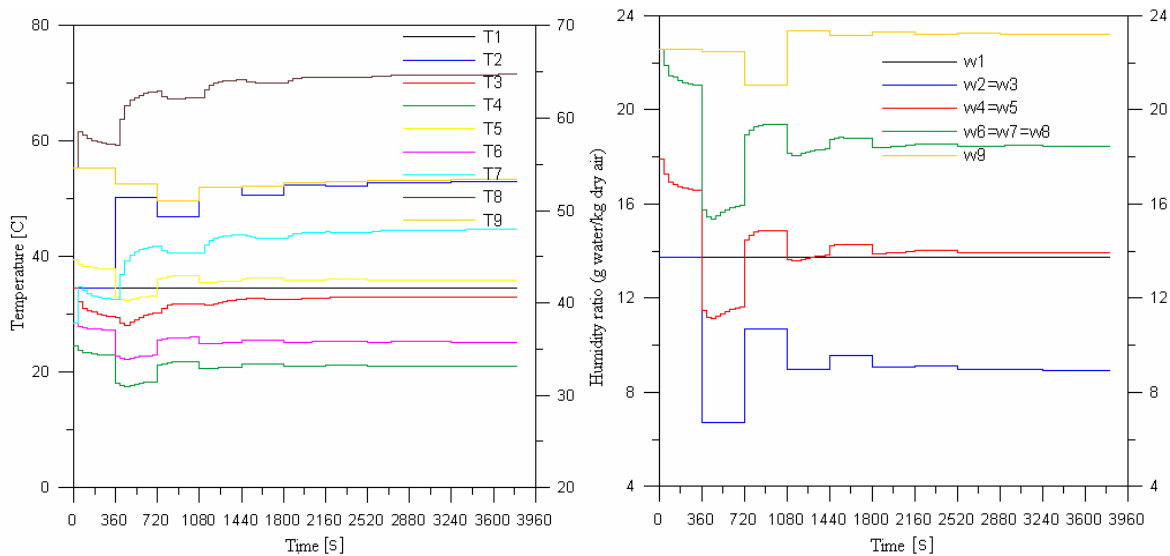

Figure 6. Evolutions of the air conditions: temperature and humidity ratio, Jin *et al.* 1998

4. STUDY OF CASE: BRAZILIAN NORTHEAST

The cooling desiccant evaporative system studied in the sub-section is a constant air-volume installation, where supply air is 100 % exterior air. Opened cycle, experimental in the laboratory of the Federal University of the Paraíba.

The following list of input data values was considered:

Initial air state in the system: Temperature 28.8 ºC and Moisture content: 18.02 g water / kg dry air

Outdoor air: Temperature 28.8 ºC and Air moisture content: 18.02 g water / kg dry air
Regeneration air: Temperature 120 ºC and Air moisture content: 18.02 g water / kg dry air
Airflow rate: process 1800 m^3/h and regeneration 600 m^3/h Heating coil: 17.36 kW
Desiccant wheel, sensible wheel, evaporative cooler and heater mounted real equipment in the laboratory.
The following list of output data values:
Output desiccant wheel (process section): Temperature 67.4 ºC and Air moisture content: 14.16 g water / kg dry air
Output sensible wheel (process section): Temperature 27.9 ºC and Air moisture content: 14.69 g water / kg dry air
Output evaporative cooler (process section): Temperature 23.0 ºC and Air moisture content: 16.75 g water/kg dry air
Room: Temperature 26.7 ºC and Air moisture content: 17.24 g water / kg dry air.
It is observed that the condition of thermal comfort in the acclimatized environment was not satisfied. To take care of such condition, a system with more than two wheels is necessary.
Cooling capacity: 7.38 kW
The calculation of the COP the systems in analysis are shown in Tab. 3. The performance of the real system was low, what it leads to believe emptying problems.

Table 3. Performance of the desiccant system in laboratory.

	Real present work
COP	0.42

5. CONCLUSION

The developed computational code for simulation of the diverse wheel is a useful tool for project and sizing of the archetype of the desiccant air conditioning system of wheels that are being mounted in the laboratory of the Federal University of the Paraíba with the advantage to be able to vary a series of parameters, such as: thickness of the desiccant one, speed of rotation, desiccant type and adsorption isotherm type. What it would not be possible to carry through with software developed by the manufacturers of such wheels that only vary the conditions of process entrances and regeneration through the temperatures, humidity ratio, mass outflows or volumetric outflows. In the desiccant system with two wheels it was observed clearly that the performance of the system depends on the individual performance of each component of the system that is proven in the numerical validation and the experimental validation. However, discrepancies are observed that can be associates to the uncertainties of the used variable and estimates of variable not supplied. It is observed that a desiccant system the two wheels do not provide thermal comfort for tested region, being necessary a configuration with three or four wheels.

6. REFERENCES

Camargo J.R., Ebinuma C.D., 2005, "An Evaporative and Desiccant Cooling System for Air Conditioning in Humid Climates", J. of the Braz. Soc. of Mech. Sci. & Eng. Vol. 27, pp. 243-247.
Ge, T.S., Li Y., Wang, R.Z., Dai, Y.J., 2008, "A review of the mathematical models for predicting rotary desiccant wheel", Renewable & sustainable energy review, Vol. 12, n. 6, pp. 1485-1528.
Gurgel J.M., 1994, "Caracterização de um Sistema de Condicionamento de Ar por adsorção Sólida em Ciclo Aberto Regenerado por Energia Solar", In: V Encontro Nacional de Ciências Térmicas – ABCM (1994).
Jin, W., Kodama A., Goto, M. e Hirose, T., 1998, "An adsorptive Desiccant Cooling using Honeycomb Rotor Dehumidifier", Journal of Chemical Engineering of Japan, 31, 706-713, 1998.
Medeiros J.M., Gurgel J.M., Marcondes F., 2007, "Effect of the Mass Diffusion Resistance in Desiccant Wheel for Humid Air Dehumidification", Proceeding of the 19th International Congress of Mechanical Engineering, COBEM 2007, UNB, Brasilia, DF, Brasil.
Nóbrega C.E., Brum N.C.L., 2006, "Mathematical Modeling of adiabatic adsorption", Proceeding of the 11th Brazilian Congress of Thermal Sciences and Engineering, ENCIT 2006, UFPR, Curitiba, PR, Brasil – paper CIT 06-1014.
Ruivo, C.R., Figueiredo, A.R. e Costa, J.J., 2004, "Predicted results of the performance of a unizone solid-desiccant evaporative cooling system", in Climamed'04, Proceedings Mediterranean Congress of Climatization, Lisboa, Portugal.
Simonson, C.J., 1998, "Heat and Moisture Transfer in Energy Wheels", Ph.D. thesis in mechanical engineering, University of Saskatchewan, Canada.
Wang, R.Z. Li, Y., 2007, "Perspectives for natural working fluids in China", International Journal of Refrigeration, Vol. 30, pp. 568-581.

7. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.