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MODELING OF COOLING EVAPORATIVE SYSTEM, WITH DESIGN AND COMPARISON BETWEEN DRIVERS AND MODERN CLASSIC USED IN CLIMATE OF ENVIRONMENTS

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Abstract: *Our planet is undergoing significant social, cultural, structural and environmental transformations. The high and increasing consumption of electrical energy is one of the great problems of humanity, involving directly in the preservation of the environment. One of the great challenges of the modern world is to improve and develop equipment and machinery to maintain the functional patterns of modern society and still preserve the nature. Within this situation we can easily find air-conditioners systems being considered broadly responsible for the high power consumption as well as the degradation of the ozone layer, also contributing to global warming. One way of solving the problem is to invest in clean energy matrices, however, another alternative is the replacement of the air conditioning systems of the vapor compression cycle for alternative systems. There are studies directed to the development of various types of conditioner systems, among these we highlight the evaporative coolers, which provide large reduction in electrical consumption, good levels of indoor air quality, thermal comfort and not environmental aggression. Evaporative cooling is a natural process which consists in reducing the air temperature and relative humidity elevated their mechanisms through simultaneous heat and mass transfer between air and water. Despite its simplicity and low cost of ownership and operation, the reduction of the temperature in evaporative cooler depends largely on the relative humidity. In this work we present a theoretical approach of analyzing the evaporative cooler. Here was developed the mathematical modeling of evaporative cooler through technical white box using the physical description of the phenomena involved. To improve system performance and ensure the parameters of temperature and humidity desired, it was designed a control system. We used classic controllers proportional (P), proportional integral (PI) and proportional integral derivative (PID) controller, as well as a modern type linear quadratic Gaussian (LQG). At the end all of these controllers will be analyzed and compared the efficiencies and power consumption with each controller. The designed control system should also ensure that the performance indicators are achieved, such as response time on maximum lift, maximum error and stability.*

Keywords: energy consumption, process control, air conditioning.

1. INTRODUCTION

Our planet is constantly changing, which increases every year and whose effects are visible. The global population growth requires high rates of degradation to the environment, as well as high consumption of our natural resources, especially in societies where growth happens in a disorganized manner. The harmful effects of this dynamic growth accumulate and makes the world face increasing problems. Two of the problems that most concern and which debate has been very intense, are related to the consumption of electricity and the effects of releasing harmful gases in ozone layer, which results in the growth of interest in the development or improvement of alternative systems whose characteristics are low power consumption and no severity of nature. Following this line of reasoning is possible to find a significant number of researches aimed to minimize these effects, the results desired are the development of systems, processes and equipment with better yields.

Modern society has been increasingly using equipment that have characteristics of high consumption, which harm nature, and were once considered luxury items, but which are now basic need items. Under this view, you can see many types of systems that have high consumption, however, no other gains such prominence how equipment designed for air conditioning and refrigeration. Air conditioners environments, refrigerators, humidifiers and dehumidifiers, used for domestic purposes, have been increasingly requested, however, also in the industrial field the refrigeration and air conditioning systems have high growth rates. In some activities, to improve the quality of manufactured products, it is necessary that entire sectors on the factory are air-conditioned, like all industrial wire, where the control of climatic conditions is required to ensure a quality standard (Braga, 2010) . To ensure the quality of some products it is necessary to apply rapid cooling and storage in air conditioned environments, in addition, the increasing production implies directly on the increased power consumption by these systems. According to Shelton (1982), about half of residential electricity consumed in the U.S. is for the purpose of air conditioning, refrigeration, ventilation and heating.

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The consequences of using such equipment on the Environment, is another problem to be solved. Closely related to the very serious problems like energy crisis and environmental imbalance, has supposedly caused various phenomena such as El Nino and La Nina. One of the serious problems that contribute to environmental imbalance is the release of toxic gases in the atmosphere, which causes the destruction of the ozone layer and also global warming. The gases that harm the most ozone layer are called HCFCs (hydro chloro fluoro carbon) and CFC (chloro fluoro carbon) used in conventional air conditioning and refrigeration systems (vapor compression system) of small, medium and large sizes, across the world. According to Sagan (1998), chlorine from cfc is responsible for the destruction of the ozone layer, and stated that one chlorine atom can destroy about one hundred thousand ozone molecules. The CFC molecule can last about 100 years in the atmosphere. It is this time that the uv rays take to break the chlorine atom of the molecule cfc and take it back to the lower layer of the atmosphere eliminating it in rainwater. Ozone is our only protection against the ultraviolet rays of the sun. If all the ozone in the upper layer was in the pressure and temperature of the sea level, the layer would have about 3 mm thick.

The development of new systems, as well as improving the performance of existing systems is a major challenge for researchers in order to create systems in line with our current reality. The precept that we must use energy rationally and still preserve the environment, within this new global consciousness, can lead us straight to HVAC systems vapor compression. Such systems have been used daily and on a large scale, for residential, commercial and industrial. It is estimated that in the United States about 50% of residential electricity consumed daily is used for the purpose of air conditioning, heating and cooling (Shelton, 1984). These refrigeration equipment and air conditioners are responsible for much of the energy consumed, mainly in the cities of medium and large sizes from tropical regions. Besides the high consumption, another major disadvantage is the release of CFC and HCFC gases into the atmosphere when the fluid change, either by damage to the compressor, corrosion in pipes or even by plugging a fluid filter. In practice there is a significant increase year by year, in the use of vapor compression systems, which can lead to a breakdown, either as energetic as environmental. The newer air conditioning systems are using gases considered as environmentally friendly such as hydro fluorocarbon (HFC) type R - 407 C and 410 A. Among the equipment highlights are the variable refrigerant flow (VRF), which besides using fluid 410 A, also work with the variable speed compressor depending on the thermal load required at every moment, which in practice represents a reduction in total energy consumption. However, VRF technology equipment presents very high costs of purchasing and installing in relation to whose conditioners compressors have fixed rotation.

The need to rethink the current model has encouraged conducting research around the world, in order to reduce power consumption and promote positive environmental impact. Research on HVAC systems by absorption, evaporative cooling and dessicant cooling are being held across the planet and with greater intensity. These cycles provide reduction in electricity consumption and do not use environmentally harmful gases as the working fluid. Alternative systems began to become evident especially after the Kyoto Protocol, which dealt with the effects of chlorofluorocarbons and hydrochlorofluorocarbons on the ozone layer, and decided in a first step to end the use of cfc from 1995 and HCFCs, in a second step, 2015 (Pons et. al, 1999). With the ratification of the Kyoto Protocol alternative systems of refrigeration and air conditioning came to be further explored, including the dessicant cooling systems have been well developed, particularly in the United States and Australia. In an attempt to establish a parallel, income alternative cycles have been constantly compared, as in the work of Mashuri et. al (1999), who made a comparison between the dissecting cooling systems and cooling cycles vapor compression. From the mathematical models and analysis of the coefficients of performance (COP) thermal and electrical, the authors manage to establish parameters of efficiency and technical and economic viability. Other researchers such as Meunier et al (1996) attempted to make comparisons to other cycles, making a match Carnot refrigeration cycle by adsorption.

Some alternative systems that have been most explored are the evaporative cooling and the compounds of dissecants rotors, which use only water and air as the working fluids, not bringing risks for the environment, as well as having reduced power consumption, besides that it does not work with compressors or pipes, which are sources of corrosion and constant preventive and corrective maintenance. The basic proposal of the dissecants coolers is air treatment from the modification of the relative and absolute humidity at the entrance and exit of the process, while in conventional vapor compression systems, the air temperature is treated and humidity are a result of this treatment. In Dessicant cooling the opposite occurs, the humidity are treated and temperature output follows this treatment. . The drying air through a silica gel wheel is the first step of the process, followed by an intermediate step which consists in heat exchange in a condenser, and finally the rewetting of the air. The intention is that the sequence of these steps provide an air treated and able to take and maintain an environment within the thermal comfort zone established in the psychrometric chart. The ability to maintain humidity and temperature within the thermal comfort zone is an important feature, since vapor compression cycles can not always maintain a desired humidity (Braga, 2003). The air conditioning system by adsorption can be used in various environments. Rane et. al (1999) proposed a cooling system for adsorptive cooling of internal spaces of a bus in India. They modeled and analyzed a adsorptive cycle air conditioning, using the waste heat of the exhaust gases as a heat source to reactivate the system. They estimated that a bus with three thermal load 7 TR (84,000 btus / h) consumes about 1.2 liters of diesel per hour of operation. This vehicle must yield of about 35% or 65% of the energy is rejected as heat as much as the exhaust exchange radiator. It is proposed that about 1/3 of the waste heat is recovered to create a new alternative cooling cycle.

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An alternative system for air conditioning, which has been used in a large number of applications in hot and dry regions, is which does the evaporative cooling process. According to Yamane (1998), this was the first HVAC system and was developed in the mid-nineteenth century. This technique can be used in combination with natural ventilation and the forced ventilation for both temperature reduction (reduction process of the heat sensitive) and to humidify the air (process of increasing the latent heat). Wiersma et. al (1983), presented a paper of this process to agriculture by analyzing the relation of velocity, temperature and air humidity, and reported the increase of production due to climate with low costs of installation and operation. They also showed the ease of assembly such a system , applied to increased production of eggs, milk, and others. Omtvedt et al (1971) and Buffington et al (1978) dealt with the influence of climate, by evaporative cooling, in people's lives, having Omtvedt (1971) given the focus on reducing fatigue due to the reduction of the air temperature. Kluppel and Leite (1989) in his paper titled Performance of a roof pond in a hot humid climate, dealt with the performance of cooling using a water box cover, while Leite and Kluppel (1993) showed an air conditioning system using a pool as cooler liabilities and Filippin et. al (1998) presented a work developed in the province of La Pampa in Argentina, a region of semi-arid climate. The evaporative cooling technique has been applied to a building area of 350 m2. Results obtained in two years of experiments were shown. Evaporative cooling, can be used for ambient air conditioning in hot, dry regions, are also used in air conditioning systems with dessicant rotor, corresponding to the last step, in other words, is responsible for air humidification at the exit of the equipment and consequently, reducing the dry bulb temperature.

Alternative systems ensure the reduction of power consumption compared to conventional systems, even the developed countries such as those using VRF technology, however, your tracks income is, in general, low. To ensure high performance of thermal systems, in particular cooling cycles alternative, it is necessary to use automatic controllers. Cooling systems vapor compression always made use of these controllers. The first automatic controllers used in refrigeration vapor compression were turn on and turn off controller. This type of controller used to control temperature operates as a function of the air temperature sucked by the conditioner (return air) which changes the resistance of the fluid contained in a bulb, and this fluid acts on the relay that switches on or off the equipment. The constructive and operational simplicity of this controller, besides the low cost, causes most air conditioners small and medium use it in order to maintain a constant average temperature, but the need for better controlling, especially in systems large and the need to eliminate the large fluctuations in response, made other controllers were developed on a commercial scale equipment. An example is the liquid coolers large (chiller), or special systems developed for industries that use classical control systems (Delgado, 2000).

The need for better control of thermal systems has become so evident that some researchers in different parts of the world are currently working in this area. Because it is two different areas of engineering, control systems or thermal process control is endowed with some degree of extra difficulty, since each system has its own thermal dynamics, where his mathematical model, experimental or theoretical, can be difficult to determine. Thus, the success of this type of work may be in creating a model that can be integrated into control systems, which requires knowledge of both areas.

Although some jobs are already being developed, many commercial thermal systems have had their income reduced by the lack of a more adequate control. Perhaps, existing difficulties in uniting researchers, disciplines and knowledge, besides the difference of approach in the treatment of the problem, analysis and display of results, are determining factors for the lack of further development of these two areas "(Braga, 2000).

Some relevant studies have been developed and attest the efficiency of the integration of control and thermal. Garcia et al (1999) studied a control strategy that enabled the optimization of temperature distribution inside a container volume. Spetios and Coonick (2000) used artificial intelligence techniques, neural networks and neuro fuzzy for prediction of hourly solar radiation on a horizontal surface. Already Alkhamis et al (2000) used a classic controller, PID type for controlling the temperature of a bioreactor fed by a solar collector. This work emphasized the importance of PID controller and compared their results to a on off controller. Kalogirou et. al (1999) studied the use of artificial neural networks to model a system of solar domestic water heating.

In the cooling area, some studies were also presented. Braga (2000) studied a classical control system applied to a heat exchanger served by evaporative cooling. The water exiting the heat exchanger should have it´s temperature controlled to serve any process. Mashuri et. al (1999) presents a work which shows the need to control the regeneration temperature of the adsorbent and the evaporative cooling process as a way to ensure a sensible heat ratio in the order to 75%, but also achieve acceptable performance levels.

The great influence of refrigeration vapor compression in electricity consumption and environmental degradation, suggests that other refrigeration and air conditioning systems are created and improved. The development of systems that use other sources of energy that do not pollute the plantet's atmosphere and with high coefficient of performance constitutes the greatest challenge of modern times. However, the performance of any system should be evaluated not only as a mathematical relationship of input and output power, but also the reflection of its consequences.

The objective of this work is to develop a system capable of when used alone or associated with alternative cooling cycles, producing a new cycle air conditioning for environments that besides its low power consumption also ensures operation within the best tracks income as well as provide satisfactory response time, stability and disturbance rejection, such as insertion of large thermal loads. For both techniques will be used classic controller PID type, as well as modern control techniques like Linear Quadratic Gaussian (LQG). The responses of the system, actuated by the controllers, are compared. Another analysis to be performed is the energy consumption of the system with different controllers.

2. MATHEMATICAL MODELING

In this section are presented the mathematical model of the white box type of an evaporative cooler, designs and mathematical models of controllers that will be used for the system. The mathematical model of the chiller will be developed in order to enable the application of the types of classic controllers like PID and LQG modern type. Mathematical models will be presented in the forms of transfer functions and state space. The controllers are designed to meet the performance specifications, so the variable should be controlled with an error and time limits laid down, as well as on specific sign.

Mathematical modeling of the evaporative cooler was performed to allow the use of control strategies, considering the incompatibility of control strategies with systems multiple input, multiple output (MIMO), typical of more conventional models. Thus, it was necessary to develop a mathematical model containing only one output, even with multiple time-variant input.

The mathematical model of the system in question was made through global analysis using mass balance and energy balance of a volume control. According to Felder and Rousseau (2008), the principle that underlies all energy balance is the law of conservation of energy which states that energy can't be created or destroyed.

We define the energy balance for open systems at steady state as the energy that goes regarding the energy that comes out, (Felder and Rousseau, 2008). For the energy balance occurs appropriately, the mathematical model can only be done after the definition of a control volume (Bejan, 1996). Figure 1 is a schematic representation of an evaporative cooler air-conditioning environment. In said process air is forced to circulate through the interior of a spray box, while a mass of water is sprayed into the air stream. These flows of water and air in direct contact inside the cooler results in the decrease of dry bulb temperature and elevation of wet bulb temperature of the air. As a result, air enters the ambient mixing mass existing air. The climatic conditions of the air in the entrance of the cold box should exhibit low humidity, which is typical of semi arid regions or coming from HVAC systems using dissecting system.

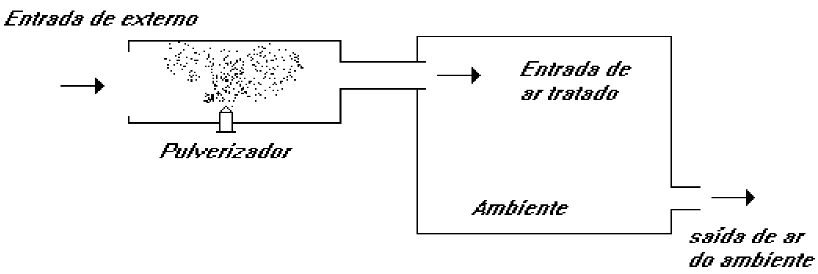

Figure 1. Scheme applied to an evaporative cooler environment.

Equation (1) represents the energy balance between the input and output of the evaporative cooler. Equation (2) represents the cooling system in transient state.

$$(\dot{m}_{ar}.cp_{ar} + \dot{m}_{ve}.cp_v).T_1 - \dot{m}_{ag}.h = (\dot{m}_{ar}.cp_{ar} + \dot{m}_{vs}.cp_v).T_2 \quad (1)$$

where: is the mass flow of circulating air, is the constant pressure specific heat of air;
is the inlet temperature of the chiller, is the outlet temperature of the chiller;
is the mass of water vapor at the input, is the mass of water vapor output;
the water flow is sprayed, it is the air mass;
is the energy of vaporization of water;
is the specific heat at constant pressure of water vapor is the energy of vaporization of water;

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The system transient state results in Equation 2.

$$M_{ar}.cp_{ar}.\frac{dT_2}{dt} = (\dot{m}_{ar}.cp_{ar} + \dot{m}_{vs}.cp_v).T_2 - (\dot{m}_{ar}.cp_{ar} + \dot{m}_{ve}.cp_v).T_1 + \dot{m}_{ag}.h \quad (2)$$

Applying Laplace transform, we have:

$$(M_{ar}.cp_{ar}.s - \dot{m}_{ar}.cp_{ar} - \dot{m}_{vs}.cp_v).T_2(s) = (\dot{m}_{ar}.cp_{ar} + \dot{m}_{ve}.cp_v).T_1(s) + h.\dot{m}_{ag}(s) \quad (3)$$

The mathematical model of the environment was realized from the energy balance between the input and the output, where equation (4) represents the system in transient state.

$$\dot{m}_{ar}.cp_{ar}.T_2 + U.A(T_1 - T_{a2}) + \dot{m}_{vs}.cp_v.T_2 = \dot{m}_{ar}.cp_{ar}.T_{a2} + \dot{m}_v.cp_v.T_{a2} \quad (4)$$

where: U is the overall coefficient of heat transfer;
A is the surface area;

Substituting (3) into equation (4), and the outlet temperature as a common term, we have:

$$T_{a2}(s) = \frac{(cp_{ar}.T_1 + cp_{ar}.T_{a2}).\dot{m}_{ar}(s) + h_{ag}.\dot{m}_{ag}(s) + U.A.T_1(s)}{(M_a.c_{par}.s + U.A)} \quad (5)$$

The equation (5) give rise to the two transfer functions given by equations (6), (7) and (8) respectively representing the plant and plant spray system disorder, which will be influenced by variations in the temperature of the incoming air spray system.

$$\frac{T_2(s)}{\dot{m}_{ag}(s)} = \frac{h_{ag}}{(M_a.c_{par}.s + U.A)} \quad (6)$$

$$\frac{T_2(s)}{T_1(s)} = \frac{U.A}{(M_a.c_{par}.s + U.A)} \quad (7)$$

$$\frac{T_2(s)}{\dot{m}_{ar}(s)} = \frac{(c_{par}.T_1 + c_{par}.T_{a2})}{(M_a.c_{par}.s + U.A)} \quad (8)$$

You can see that the system will be changed whenever the dry bulb temperature of the incoming air cooler is modified. It also follows that the proposed system presents this variable recursively, since it is associated with the air mass which is also variable. Thus, to solve the equations recursive terms are simulated from the minimum to the maximum value, assuming the condition most unfavorable response.

3. DESIGN OF CONTROLLERS

The realization of the design of a suitable controller should consider the type of system that is being worked on, as well as the dynamic characteristics of the system. The following describes the actions of classical control, and features proportional, integral and derivative, as described by Ogata (2003) .. There are several techniques for controller design classics, here is the criterion of Ziegler and Nichols. It will be necessary that the values of parameters of Equations (6) and (7) are assigned. The values of the terms of the equations defining the dead time, time constant and the gain of the coupled system, resulting in the definition of dynamic behavior.

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The values of the terms in equations (6) and (7) are defined as follows:

h_{ar} = 600 $\frac{kcal}{kg}$; cp_{ar} = $0{,}24\frac{kcal}{kg.^{o}C}$; m_{ar} = 1 $\frac{kg}{s}$; m_{v} = 0,04 $\frac{kcal}{kg.^{o}C}$; c_{pv} = 0,446 $\frac{kcal}{kg.^{o}C}$; M_{a} = 10 kg; U = 1 $\frac{kcal}{h.m^{2}.^{o}C}$; A = 10 m^{2};

Thus, equations (6), (7) and (8) give rise to equations (9), (10) and (11) respectively.

$$.\frac{T_2(s)}{\dot{m}_{ag}(s)} = \frac{(-600.)}{2.4s+1} \tag{9}$$

$$.\frac{T_2(s)}{T_1(s)} = \frac{1}{2{,}4s+1} \tag{10}$$

$$.\frac{T_2(s)}{\dot{m}_{ar}(s)} = \frac{1{,}2}{2{,}4s+1} \tag{11}$$

3.1. Proportional Integral Derivative (PID).

To perform the classic controller design methods were used to Ziegler and Nichols. From the application of this methodology was possible to measure the drivers and hence calculate the proportional gain, integral and derivative. After calculation of earnings was necessary to perform an adjustment to optimize the controller in order to bring the system responses that meet performance specifications.

The controller design, carried out by the method of Ziegler and Nichols, underwent final adjustments to suit the performance specifications. The controller gain obtained for each controller and containing the final adjustments are presented in the results section.

3.2. Optimal Control (LGC)

For the controller design Great, LQG, it was necessary to pass the mathematical model developed in section 2, the form of the transfer function to state space.

The plant in the state space, was modified again. The mathematical model was generalized, resulting in another model, known as the generalized plant, this format was not included in the dynamics of the disturbance. For the controller design was necessary generalization of an integrator. Later there was the widespread association of the plant with the generalized integrator. The matrices Q and R were defined as 1 xC'xC and 0.25, respectively. The application of the LQG method resulted in the controller shown below.

$$.Gc_{lqg}(s) = \frac{1{,}0396s + 0{,}25}{s^3 + 1{,}8430s^2 + 1{,}4433s + 0{,}0001}$$

4. RESULTS

Below are the responses of systems actuated by PID and LQG controllers.

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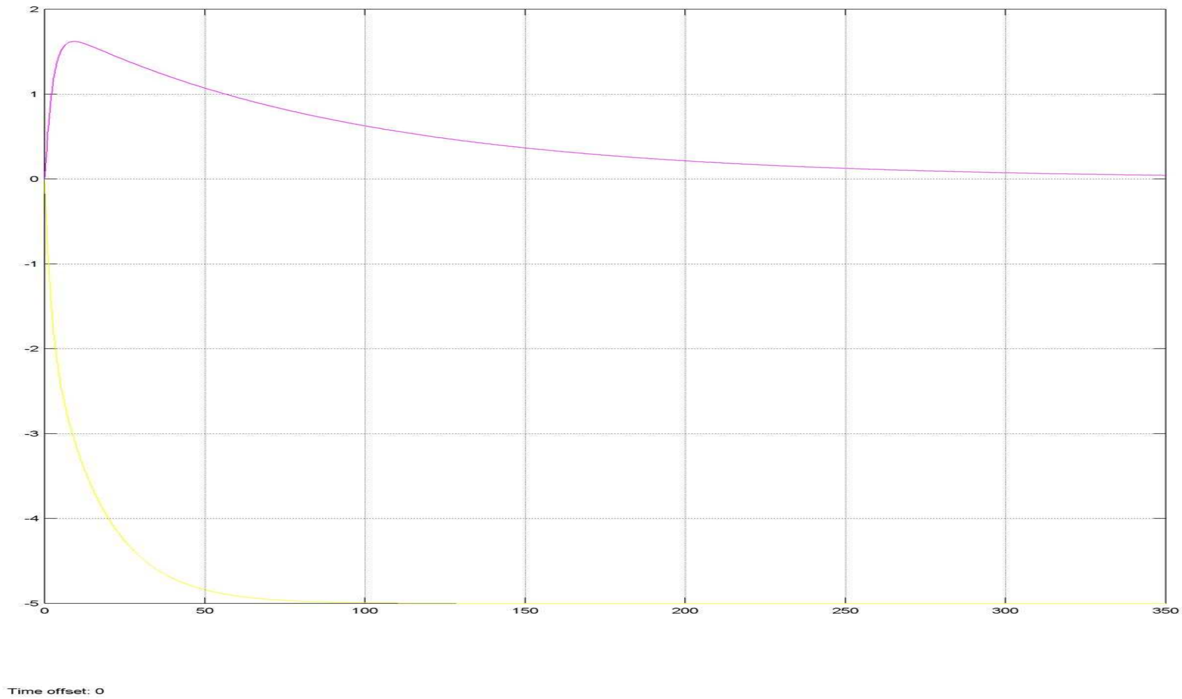

Figure 1. Graph Response System Coupled actuated PID Controller

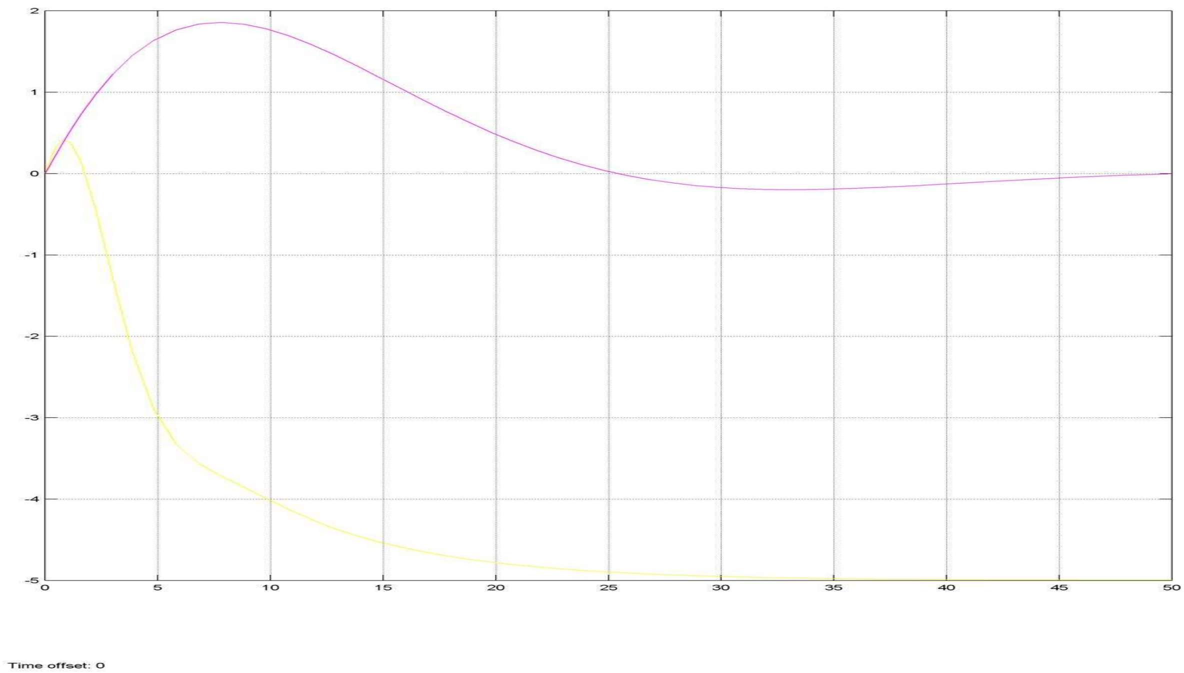

Figure 2. Graph Response System Coupled actuated LQG Controller

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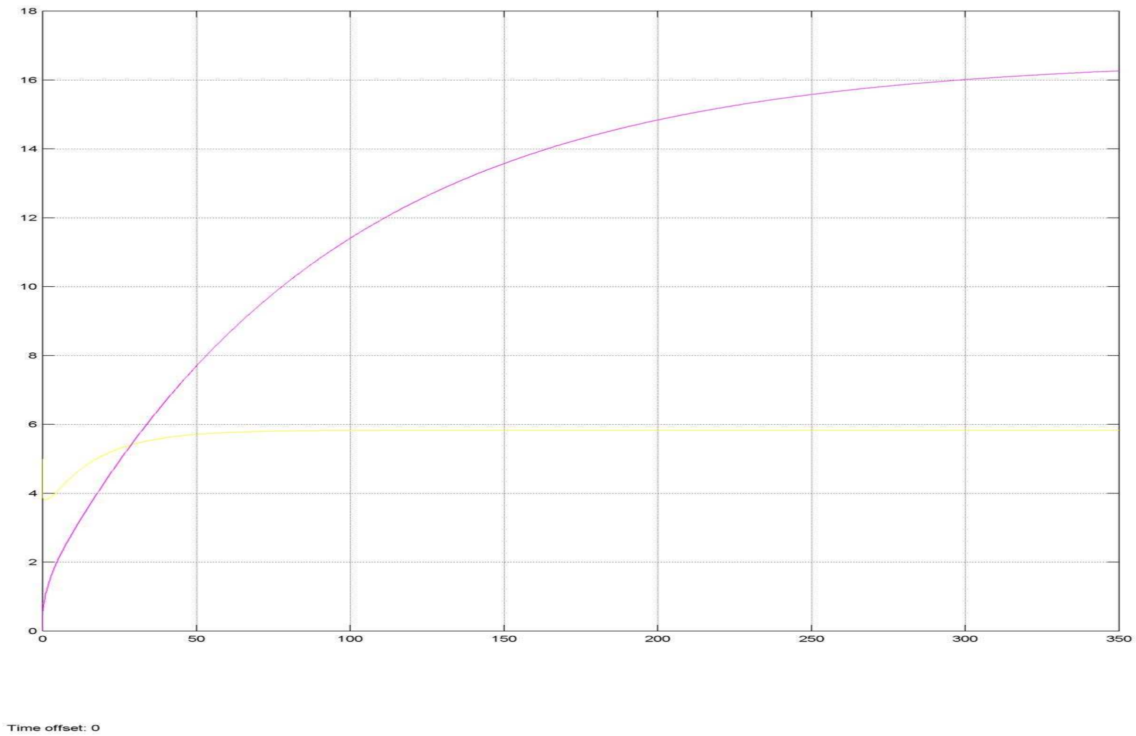

Figure 3. Graph of Variable Control System Coupled actuated PID Controller

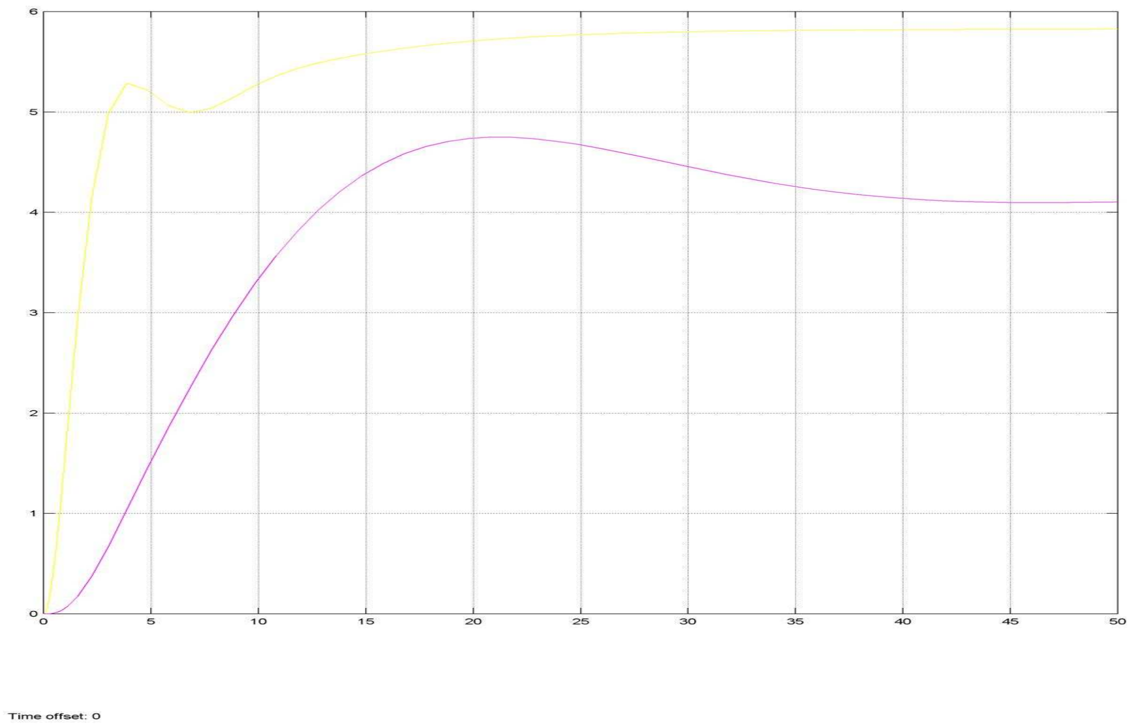

Figure 4. Graph of Variable Control System Coupled actuated LQG Controller

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Both strategies can take control and maintain the system desired conditions. Figure 1 shows the system response actuated by a PID controller for the servo system and a regulator. The purple curve shows the system response regulator, which after receiving a disorder, or a heat source permanent able to completely eliminate the error in about 320 seconds. The yellow curve represents the response of the servo system, which makes the dry bulb temperature of the environment is reduced from 30 C to 25 C, or a variation of 5 C in 100 seconds. Figure 2 shows the system response controlled by a LQG. You can see that this controller eliminates the error in the system in about 50 seconds. Also that in 45 seconds the dry bulb temperature is reduced by 5 C. The controller LQG shown much faster than the PID, however, it is found that the signals produced on the LQG is a little larger than those produced by the PID.
Another important parameter to be considered is the control signal, since it indicates the amount of energy consumed. Figure 3 shows the control signal to the servo and regulatory systems produced by the PID controller. The purple line represents the system controller, while yellow line shows the servo system. Figure 4 shows the control signals produced by the LQG controller, and the purple line the regulatory system and the yellow servo system.

5. CONCLUSION

It is possible to observe that both strategies can control the proposed system. Analyzing the results it is concluded that the coupled system controlled by a system LQG produces better results than those given by the PID controller. The response times are provided by the LGC, on average, half of those produced by the PID controller. However, the results show that gains are higher when subject to the control signals. It is concluded that the quantity of energy consumed for responses are much smaller when we use the LQG controller. This result is especially important when one considers that the HVAC system is an alternative to conventional and aims to reduce electricity consumption.

We further note that the variable control system, controlled by PID increases a lot. This practice implies a high flow within the environment. The consequence of this is an increase in discomfort due to air velocity, drag capable of papers and light objects.

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7. RESPONSIBILITY NOTICE