Evaluation of the PID and On-off control logics in the environment conditioning using a thermal storage system with ice bank

Klicia Sampaio[1], Vivaldo Silveira [1]; Marcos Afonso[2]

1- Food Engineering Department – College of Food Engineering - Unicamp
2- Food Technology Department – College of Food Engineering - UFC

Corresponding email: klicia@fea.unicamp.br

SUMMARY

The thermal storage systems have as main objective the rationalization of the demand of electric energy, due to the use of it in periods of the low demand, beyond the reduction of the initial investment. One of the means more used for accumulation of latent heat is the ice, due to its bigger capacity of storage of energy in a single volume and also because it always casts in a fixed temperature. The conventional logics of control are widely used in accordance with the necessity of the process. In this work it was used thermal storage with ice bank and it was evaluated the efficiency of the performance of controllers On-off and PID in the control of the temperature of three different environments, after ambient disturbances not measured of thermal load provoked by the variation of the external ambient temperature and/or equipment operation, activities of people and others.

INTRODUCTION

The GREGOR *et al*. [1] showed that the equipment and systems that supply thermal comfort and internal air quality for commercial environments, consume about 42% of the used energy total in the majority of conditional environments, therefore they are the main point in the discussions on energy consumption.

A thermal storage system is that one that exchanges heat with the accumulator mean during the lower demand periods, storing energy at low temperature, “cold”, to be used in the higher demand periods [2].

The ways commonly used for latent heat accumulation are: water-ice and phase change materials (PCM). These ways differ in the amount of stored energy per volume unit, in the temperature in which they store “cold” and “heat”, and in the physical conditions of the stored energy [3].

In the case of thermal storage with ice, the frozen water temperature which flows in the air conditioners is lower, reducing the ventilated air outflow for the environments, consequently reducing the costs of the fans and in the ducts, what it allows an environment humidity reduction and an increase of the comfort and the interior air quality [4].

The main objective of a control system is to make the process operate in a steady way, in accordance with the established values for process conditions and variables [5]. The used control logics can be conventional or not conventional, and the conventional ones are On-off, P, PI and PID types, and they can be very used depending on the process necessity [6].

The buildings thermal automation increases potentiality the energy management, through the supervision graphical screens implementation that provide a general monitoring of the system, resulting in a better control of the energy use and in a higher thermal comfort to its occupants.

Considering what have been showed, the experiment proposes to evaluate the temperature behavior of the rooms 1, 2 and 3, using the PID and On-off control logics with 0,5 ºC band in operational conditions of commercial environments. These environments will be submitted to changeable thermal load, which it’s directly related to the external environment, with its occupants and the materials inside the rooms, whose influence in a thermal load increase.

METHODS

In this work the ice bank was used as the thermal storage system, for temperature conditioning of three different environments. Its load was done during the night, when the refrigeration system cooled a propylene-glycol solution that was pumped internally to an immersed coil in a tank with water. Then ice was formed externally on the coil surface, resulting in a mixture of ice and water at 0ºC.

During the day, the water of the tank was pumped to the environments, where the fan-coils were located, which their function was to do the distribution of the “cold”, proceeding from the frozen water, in a uniform way to all the environments. The scheme of cooling water coming from the city treatment stations and the distribution of the water frozen to the study environments can be seen in Figure 1.

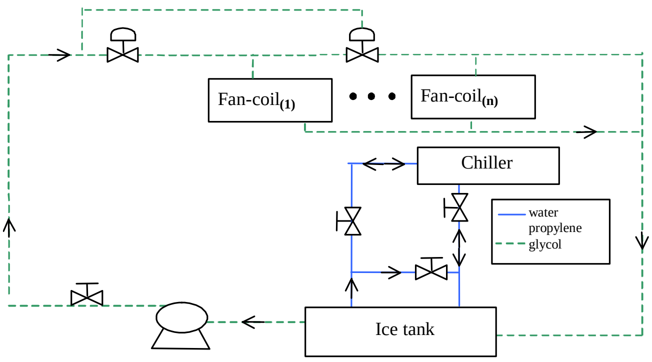

Figure 1 - Schematic diagram of the thermal storage circuit and frozen water distribution.

The temperature of each environment was controlled through On-off controllers with 0,5 ºC band and PID, where those acted directly on the control valve of frozen water outflow. This frozen water is proceeding from the ice tank, and then it’s pumped and sent to the study environments, in accordance with the necessity for the desirable temperature maintenance. The PID was tuned by the Ziegler Nichols Reaction Curve method, where it makes step disturbances in the manipulated variable and observes the received reply from the controlled variable.

The On-off controllers evaluation with 0,5 ºC band and PID was made after the ice bank load, with disturbances in the frozen water distribution, then verifying the stabilization of the rooms temperatures around the set-point. These disturbances were performed during the commercial period (8:00 A.M. to 18:00 P.M.) and the imposed thermal load to environments was proceeding from the temperature variation of the external environment, daily activities of the people and equipment.

RESULTS

After the non-measured disturbances with thermal load for all the environments, and both On-off controllers with 0,5 ºC band and PID, it was gotten the internal temperatures behavior for each environment. Figure 2 shows the internal temperature behavior of room 1 under controller PID performance.

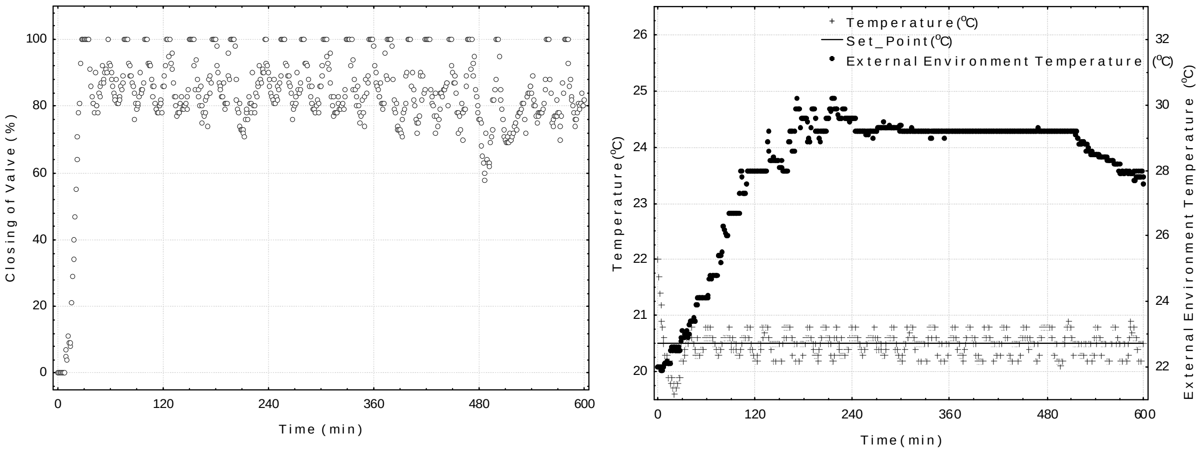

Figure 2 - Internal temperature behavior of room 1 under controller PID performance.

The beginning of the experiment occurred with the definition of the room temperature set-point in a value below the environment value. Thus the controller action, in the beginning of the environment cooling process, was opening the valve until its temperature to reach the desired value. Then the controller modulated the frozen water valve outflow so that the environment temperature was kept around the set-point, even with great variation of the external environment temperature.The Figure 3 presents the internal temperature behavior of room 2 under controller PID performance.

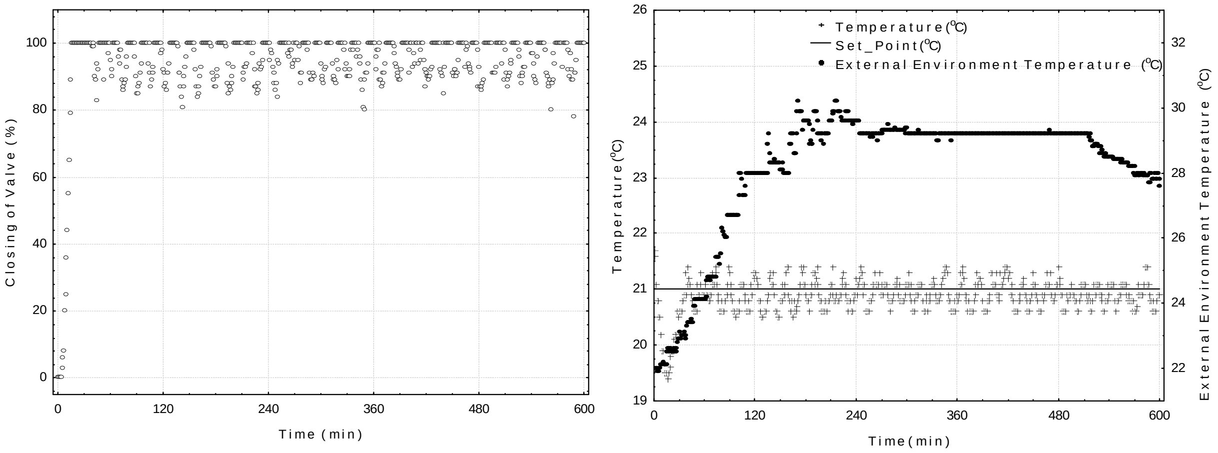

Figure 3 - Internal temperature behavior of room 2 under controller PID performance.

For the room 2 environment the controller performance is also observed so that its temperature reaches the desired initially value. However, there's a better stabilization around the set-point due to the lower heat variation tax in this environment what it is directly related with lower solar incidence index and consequently lesser control valve modulation.

Figure 4 shows the internal temperature behavior of room 3 under controller PID performance with the respective performance of its control valve, which allows higher or minor frozen water outflow in accordance with the measured error by the controller.

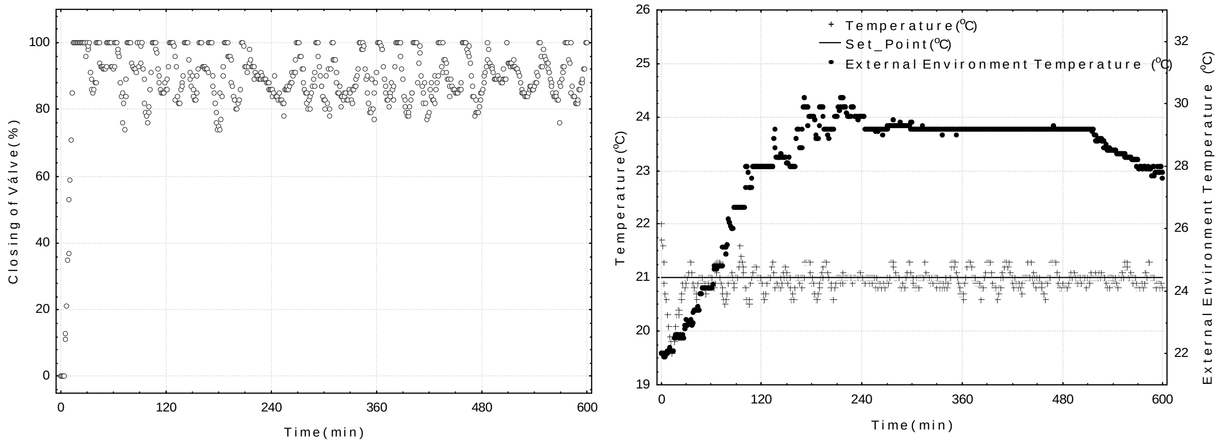

Figure 4 - Internal temperature behavior of room 3 under controller PID performance of.

Initially it was verified the control valve opening with the release of a higher frozen water outflow, occurred in function of the great value of the error (desired value little real value) in the beginning of the process. That caused the reduction of the study environment temperature.

With the reduction of the temperature, the controller compared the desired value (set-point) with the real value resulting in lower error values. In this way, the control valve modulation started to be made thus the temperature of the study environment was kept oscillating around the set-point with small variations, during all the conditioning process. In Figure 5 the internal temperature behavior of room 1 under the On-off controller performance with 0,5 ºC band can be observed.

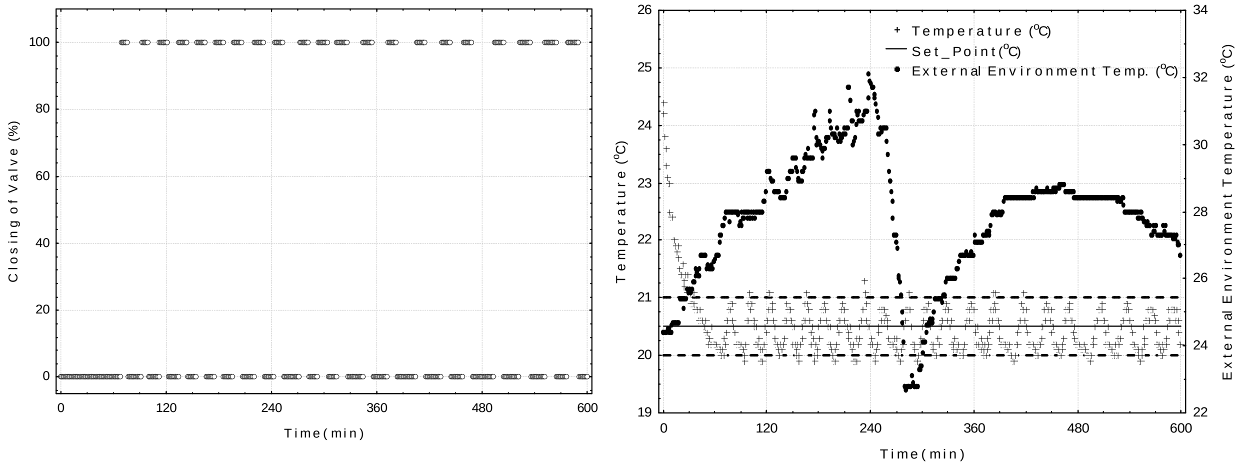

Figure 5 - Internal temperature behavior of room 1 under On-off controller performance with 0,5 ºC band.

It is verified initially that there's reduction of the internal environment temperature until the desired value and then starts the modulation of the water frozen outflow control valve for the maintenance of the environment temperature around set-point. It can be evidenced that the controller acted in a way to stabilize the set-point between the established band, even with a brusque variation of the external ambient temperature in a certain day period, provoked by a sudden rain. In Figure 6 the internal temperature behavior of the room 2 under On-off controller performance with 0,5 ºC band can be observed.

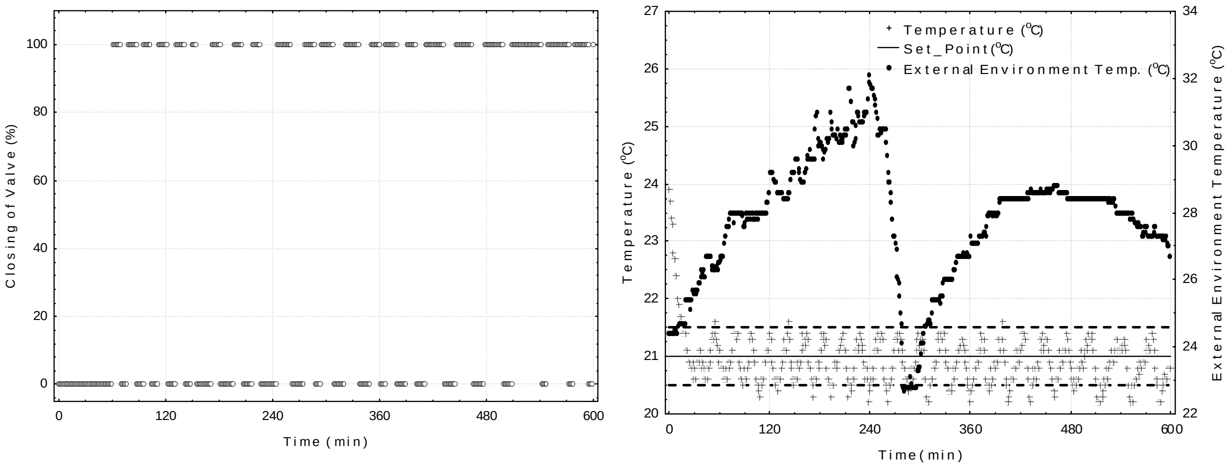

Figure 6 - Internal temperature behavior of room 2 under On-off controller performance with 0,5 ºC band.

For environment 2 it can be evidenced that even with the control valve of water outflow frozen closed during most of the experiment time, there was a higher temperature oscillation of this room comparing to room 1. It happened due to the proper controller, who is on-off type, where the temperature variation can reache values beyond the programmed band (0,5 ºC), and also due to a higher tax variation of the environment temperature, provoked by the greater number of people present. Figure 7 presents the internal temperature behavior of room 3 under On-off controller performance with 0,5 ºC band, with the respective performance of its control valve, that allows the passing of a higher or minor frozen water outflow in accordance with the existing temperature difference.

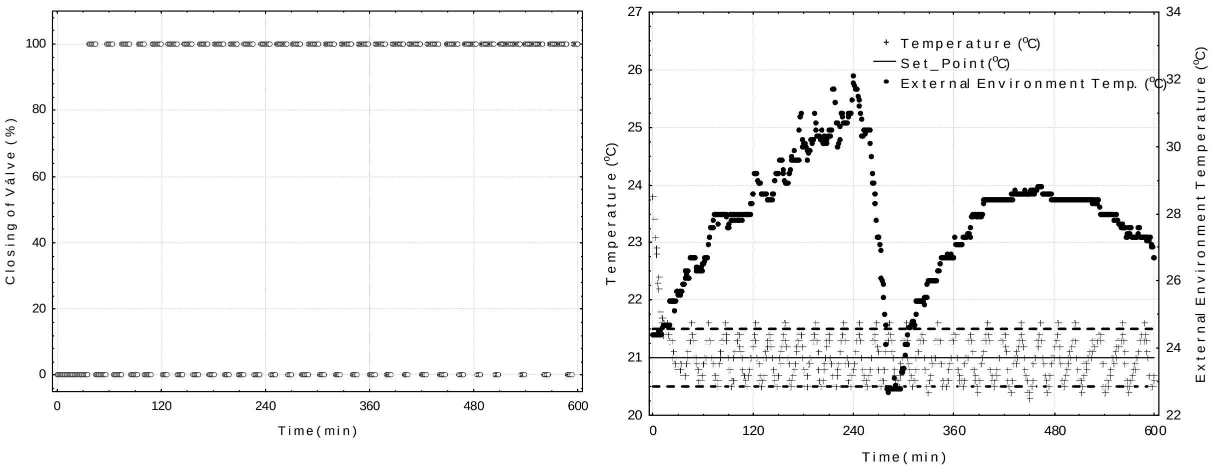

Figure 7 - Internal temperature behavior of room 3 under On-off controller performance with 0,5 ºC band.

It can also be observed for this experiment that in the beginning of the experiment the environment temperature was sufficiently high, needing a faster action of the controller in opening the control valve of frozen water outflow, thus remaining open for a higher time period, when compared with PID controller for the others experiments, that worked with conditions more suave f the internal and external ambient temperature.

DISCUSSION

From the results gotten for both controllers, On-off with 0,5 ºC band and PID, tuned by the Ziegler Nichols Reaction Curve method, can be concluded that those behaved in satisfactory way, keeping the environment temperature around the set-point with small oscillations, what it is perfectly acceptable, because the external environment that supplied most of the thermal load to the study environments that also suffered constants changes provoked by the reduction or increase of the solar light.

Applying a more detailed evaluation of the controllers efficiency as for the presented oscillations, it is evidenced the PID controller superiority, who makes a sharper adjustment around the set-point, keeping the environments temperature more steady, due to the exploitation of the particular characteristics of each action of control, in order to get a significant improve of the transitory behavior and in permanent regimen of the controlled system.

In case that the use of the controllers do not take into account a higher or minor oscillation of the temperature around the set-point (desired value), it's recommended the use of the On-ff controller with 0,5 ºC band, due to its easiness of implementation, lower operation cost during almost all tests period between the stipulated work band in accordance with the upper/lower limits of the control program.

ACKNOWLEDGEMENT

This work is supported by Coordination of Perfectioning of Superior Level Staff and the Piratininga Company of Force and Light in Brazil.

REFERENCES

1. GREGOR, P.H.; FELSMANN, C.; KNABE, G. Evaluation of Optimal Control for Active and Passive Building Thermal Storage. *International Journal of Thermal Sciences*, v 43, pp. 173-183, 2004.
2. ASHRAE Handbook – *Thermal Storage*, – Applications, Parsons, R.A. United States of America. pp 33.12, 1999.
3. DORGAN, C. E.; ELLESON, J. S. Design guide for cool thermal storage. Atlanta, Georgea: ASHRAE Inc., 1994.
4. WULFINGHOFF D. R. Chiller Plant. Energy Efficiency Manual. Maryland: Energy Institute Press, 1999. Cap. 2, pp. 405-436.
5. SILVA, F. V. Comparação do desempenho de um sistema de refrigeração para resfriamento líquido controlado a diferentes modos de controle. Campinas, 2003. 327p. Tese (Doutorado em Engenharia de Alimentos) – Faculdade de Engenharia de Alimentos – Universidade Estadual de Campinas.
6. OGATA, K. Modern Control Engineering. 3. ed. New Jersey: Prentice Hall International, 1997.