Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 54 (2014) 448 – 454

Energy Procedia

4th International Conference on Advances in Energy Research 2013, ICAER 2013

Performance Evaluation of a Guarded Hot Box U-value Measurement Facility under Different Software Based Temperature Control Strategies

Amrita Ghosh[a], Supratik Ghosh[b], Subhasis Neogi[a,b]*

[a]School of Energy Studies,Jadavpur University,Kolkata 700032,India
[b]School of Energy Studies,Jadavpur University,Kolkata 700032,India

Abstract

Energy conservation and energy management can be achieved in buildings by reducing the load on the HVAC systems used in the buildings. This is possible by reducing the magnitude of heat flow through the building materials and components such as the windows, ceilings, floors, walls, etc. The thermal performance of a material can be evaluated by measuring its overall heat transfer coefficient or the U-value. The U-value of a material can be measured using the Guarded Hot Box method. The setup comprises of three parts – the metering box, the guard box and the cold box. In this method a constant heat flow needs to be maintained through the test specimen from the metering box to the cold box. Thus it is important to control temperatures in all the three parts accurately. In the present work the temperatures of the metering box and the guard box have been controlled using three different software based temperature control strategies. In the first two strategies on-off control was implemented while in the third strategy proportional control was implemented. From the experimental data it was found that similar performances were obtained in the first two test cases where the temperatures could be controlled satisfactorily. Whereas, in the third case steady state offset was obtained while controlling the metering box temperature and the guard box temperature showed fluctuations.

Selection and peer-review under responsibility of Organizing Committee of ICAER 2013

Keywords: Guarded Hot Box; Proportional Controller; On-off Controller; Temperature; PID

* Corresponding author. Tel.: (033) 2457-2907.
E-mail address: neogi_s@yahoo.com

Selection and peer-review under responsibility of Organizing Committee of ICAER 2013
doi:10.1016/j.egypro.2014.07.287

1. Introduction

U value expressed in $W.m^{-2}.K^{-1}$ is a measure of heat loss (or gain) through a building element such as a wall, floor or roof. It can also be termed as 'overall heat transfer co-efficient' and measures how well parts of a building transfer heat. This means that the higher the U value the worse is the thermal performance of the building envelope. A low U value usually indicates high level of insulation. They are useful as it is a way of predicting the composite behavior of an entire building element rather than relying on the properties of individual materials. Thus measurement of U-value helps in achieving energy conservation in buildings.

As per the statistics (2009) provided by International Energy Agency, in India energy consumption in the residential and the commercial and public services sectors constitute about 40.84% of the total energy consumption in all the sectors[1]. PID controller stands for Proportional, Integral and Derivative controller. This type of controllers is useful in systems in which the output of the sample is compared with the desired result of the sample and to take corrective action to force the controlled element closer to the desired result or set-point. PID controllers can be used to control temperatures over a wide range such as very low temperature in adiabatic demagnetization refrigerators [2] or high temperature in gas-fuel combustors [3]. The on-off controller is the simplest and most commonly experienced type of control. The controller acts on the on-off logic. In this system the device to be controlled is either fully on or off with no intermediate operating positions. For heating control, the heating device is switched on when the temperature is below the set point, and off above set point.

2. Guarded Hot Box U-Value measurement facility

The U-value of a material can be determined with the help of Guarded Hot Box method. In the present work the setup has been constructed following the standards BS EN ISO 8990:1996[5] and BS 874:Part 3:Section 3.1:1987 [4]. The overall test setup comprises of a metering box, a guard box and a cold box as shown in Fig.1.

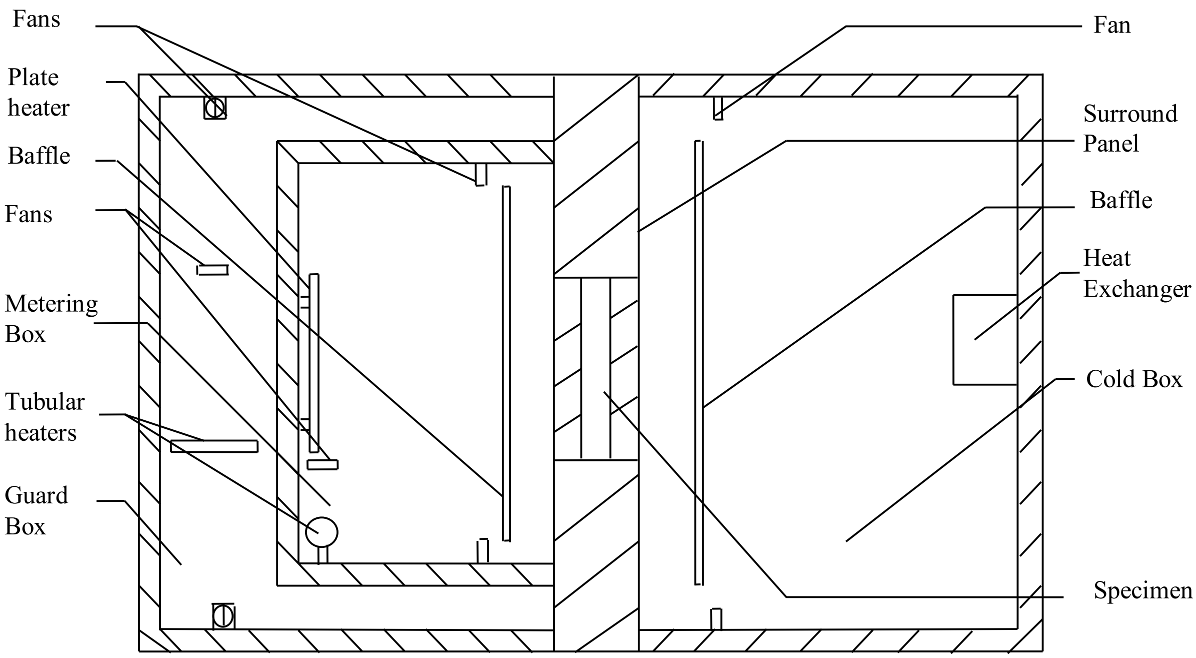

Fig.1.Guarded Hot Box U-Value Measurement Setup [6]

The element which is to be tested is placed in an aperture between the cold box and the guarded metering box. Heat supplied to the metering box passes through the test element to the cold box. The cold box is to be maintained at a constant low temperature. The U-value of the sample can be calculated by measuring the difference of temperature across the test sample and the heat flux through the test element using the formula:

$$U = \frac{Q}{A\Delta T} \tag{1}$$

Here Q (W) is the heat flow rate through the test specimen, A (m^2) is the area perpendicular to the heat flow, ΔT (K) is the temperature difference across the specimen.

2.1 Metering Box

The heating units are placed in the metering box which supplies heat. As a result of that the apparatus reaches the desired set point temperature gradually. To prevent the air flow between metering box and guard box the one open side of the metering box is pressed against the test element. The walls are well insulated to prevent the heat loss through the sides and back of the metering box. For providing a radiating surface of uniform temperature a baffle plate is placed parallelly to the surface of the test element. Two types of heaters are used in the metering box i) A 100 W plate heater ii) two 60 W tubular heaters. These heaters are used to heat the metering box to reach a particular temperature. Circulating fans are also installed in the metering box for bringing uniformity in the temperature.

2.2 Guard Box

In the guarded hot box the metering box is kept inside the guard box. The heat flow through the metering box walls is minimized by maintaining the guard box temperature at a desired level. To minimize the effect of changes in the laboratory environment temperature on the test element in the metering area, adequate width of the guarded space is provided. The guard box is well insulated to reduce the heat loss to the surrounding environment. Two 120 W tubular resistance heaters are used. For avoiding stagnant hot or cold spots circulating fans are installed in the guard box.

2.3 Cold Box

Using a chilled circulating medium (ethyl glycol and water mixture) and a heat exchanger the cold box provides a controlled environment at a constant low temperature. Cold box is also highly insulated to reduce the load on the cooling system and the temperature control is achieved via PID controller. To achieve uniformity in the temperature circulating fans are installed [6].

3. Experimental details

During the test the temperatures of the metering box and the guard box are controlled. An insulation plank is used in place of the specimen. K-type thermocouples are installed to measure the air temperatures and surface temperatures at different locations of the metering box and the guard box. K-type thermocouples has a wide operating temperature range (-200 °C to 1400 °C). The voltage signals obtained from the thermocouple junctions are logged sequentially by the Agilent Data Acquisition Systems 34970A through its multiplexer slots. The air temperatures at three different locations in the metering box are measured by using the thermocouples. In the guard box air temperatures at two different locations are measured. The acquired air temperatures are logged through the data acquisition system and then fed into the computer. In the program three air temperatures of the metering box and the two air temperatures of the guard box are averaged out individually. These are used as the input signal parameters for the virtual temperature controllers. In the program two individual temperature controllers are designed to control the temperatures of metering box and the guarded hot box separately. The output signals coming out of the controllers are fed to the DAC slot for converting the signal into an analog signal. A 12V DC voltage is obtained from the DAC depending on the output of each controller. This DC voltage is processed electronically and used to operate control relays. These relays are used to operate the heating units installed in the metering and guard box.

In the present work the set point temperatures were fixed at 40 °C and performances of the system were evaluated and compared by using different control strategies. The AC circulating fans of the guard box were operated at a power of 30W to reduce the heat dissipation from the fans. This helped in maintaining the temperatures at the desired level. In these three cases the cold side of the Guarded Hot Box setup was maintained at certain low temperatures. In the metering box, the average of the three air temperatures was compared with the set point to get the error signal. This error signal was used to drive the controller. Similarly, in the guard box, the average of the two air temperatures was used to obtain the error signal.

Case 1: In the first case the Controller output was evaluated with PID logic, and then on-off control was implemented. For this case the average ambient temperature for the test period was found 28.5 °C. The set point temperature of the cold side was 0 °C, though after a certain time the temperature began to rise. The time-temperature characteristic obtained in this case is shown in Fig.2.

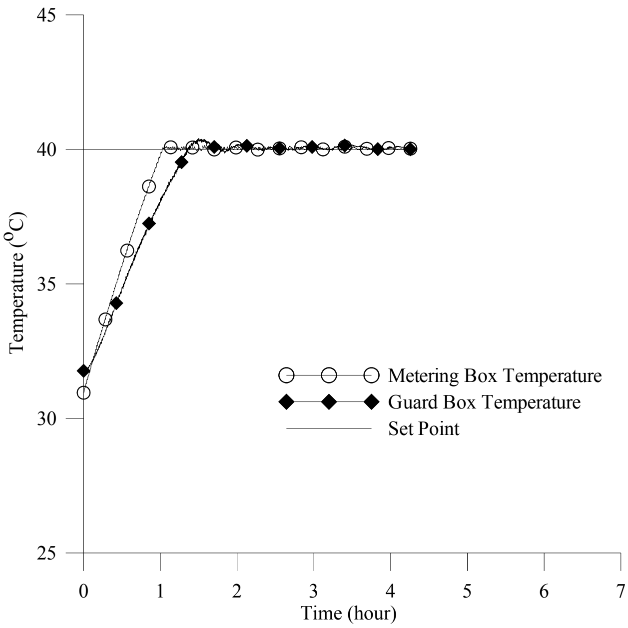

Fig. 2. Time –Temperature Characteristics for case 1

Case 2: In the second case the Controller output was evaluated with P logic, and then on-off control was implemented. For this case the average ambient temperature was found 29 °C. The set point temperature of the cold side was -5 °C, but the system could not be cooled up to that temperature. The minimum temperature attained by the cold side was -2.4 °C, after which it started increasing. The time-temperature characteristic obtained in this case is shown in Fig.3.

Case 3: In the third case P control was implemented by controlling the duty cycle of the heaters. The average ambient temperature was found 33 °C. In the third case the controller output was calculated using the Proportional term only and this output was used to control the duty cycle of the heating units in the metering box and the guard box. The set point in the cold side was set at 0 °C. A proportional band of 5 °C and a cycle time of 10 seconds were selected. Thus, until the temperature reached 35 °C the heating units were operated at full power continuously. Once the temperature crossed 35 °C the on-time of the heating units was calculated on the basis of the controller output. Thus the duration of the on-time was proportional to the error. The time-temperature characteristic is shown in Fig.4

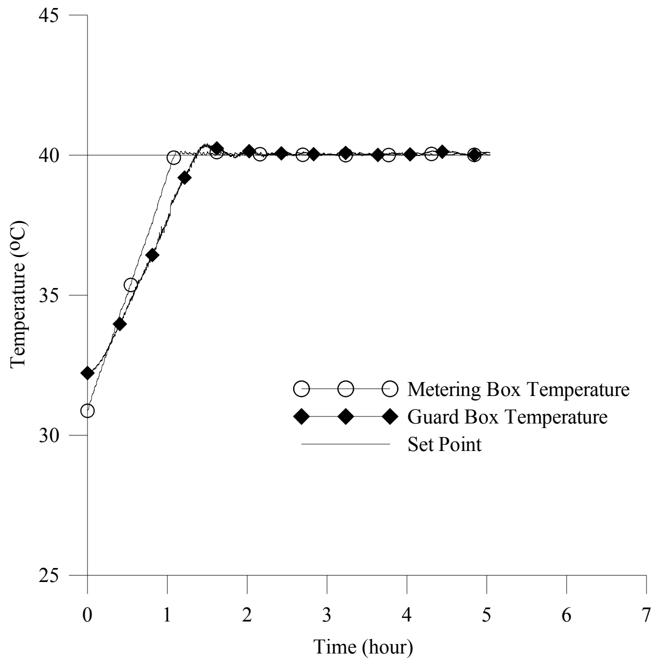

Fig. 3. Time –Temperature Characteristics for case 2

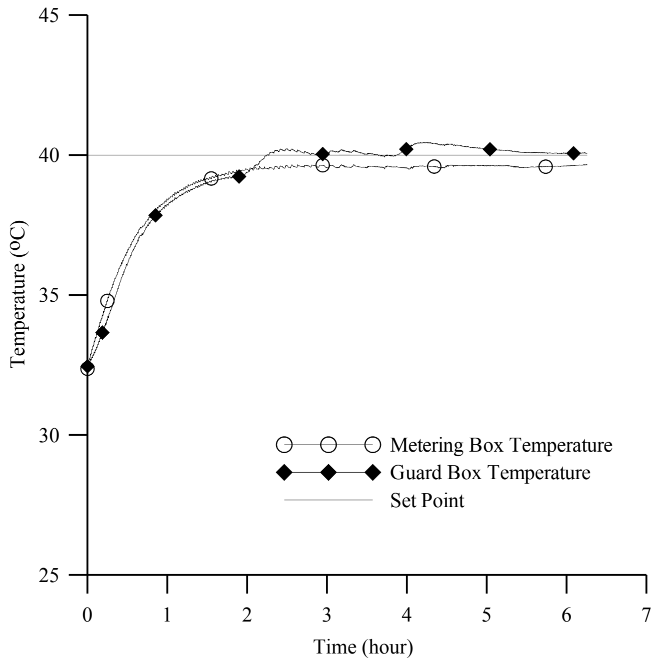

Fig. 4. Time –Temperature Characteristics for case 3

4. Performance evaluation of the system

The experimental data obtained from the three test cases with the set points of 40 °C were analysed statistically to calculate the fluctuations and the Root Mean Square Deviations. For case 1 and 2 the calculations were done after the temperatures reached the set points. Whereas, for case 3 the calculations for the metering box were done after the temperature reached the steady state and for the guard box after reaching the set point. The result has been summarised below.

Table 1. Performance evaluation of the system.

Performance Parameters	PID logic	P logic	P logic with duty cycle control
Minimum metering box temperature after reaching set point (steady state for case 3)	39.95 °C	39.97 °C	39.49 °C
Maximum metering box temperature after reaching set point (steady state for case 3)	40.15 °C	40.14 °C	39.67 °C
Maximum fluctuation (offset for case 3) of the metering box temperature from the set point	0.3762 %	0.3572 %	1.27 %
Achieved metering box temperature range after reaching set point (steady state for case 3)	0.2044 °C	0.1772 °C	0.1792 °C
Root Mean Square Deviation of the metering box temperature from the set point	0.0500 °C	0.0456 °C	0.4042 °C
Minimum guard box temperature after reaching set point	39.86 °C	39.88 °C	39.93 °C
Maximum guard box temperature after reaching set point	40.41 °C	40.41 °C	40.46 °C
Maximum fluctuation of the guard box temperature from the set point	1.03 %	1.04 %	1.15%
Achieved guard box temperature range after reaching set point	0.5495 °C	0.5359 °C	0.5281 °C
Root Mean Square Deviation of the guard box temperature from the set point	0.1149 °C	0.1015 °C	0.2027 °C

5. Results and discussions

While analyzing the data of these test cases, it can be seen that the controllers with PID and the P logic showed almost similar results. In these cases on-off control was implemented on the basis of the controller output. The controller output was calculated using PID and P logics respectively.

Usually, the integral action is provided to eliminate the steady state error or the offset which is obtained by using proportional control only. The controller using the Proportional control logic itself was capable of eliminating the steady state offset since the heating units were operated at full power whenever the controller output was positive, irrespective of the magnitude of the output. As the cold side was maintained at a temperature much below the ambient, there was much larger heat flow through the specimen to the cold side. This helped to bring the required stabilizing effect, which is generally offered by the Derivative control action.

Thus, the on-off controllers with PID and the P logic offered similar performance.

In case 3 the average steady state offset for the metering box temperature during the last 3 hours of the experiment (after the metering box temperature reached the steady state) was found to be 0.403 °C. In case of the guard box temperature, fluctuations were obtained. This may be due to the presence of low circulating air velocity in the guard box. However, the experiment should have been continued for longer duration of time to obtain the actual system performance. In this case the experiment could not be continued since the cold side temperature started increasing.

6. Conclusions

From the experimental data it is observed that the on-off control systems with PID and P logic showed almost similar performance. The maximum fluctuations for the metering box temperature from the set point obtained in these two cases were 0.3762 %and 0.3572 % respectively. These values are within the maximum limit of 1% as specified in the standard BS 874: Part 3: Section 3.1:1987 [4]. For the guard box the maximum fluctuations were 1.03% and 1.04% respectively. However the fluctuations of the guard box temperature gradually decreased with time.

In the third case of duty cycle control the average offset obtained for the metering box temperature was 0.403 ^{o}C. The controller needs to be tuned in order to minimize the offset. For the guard box temperature, fluctuations were obtained probably due to the low circulating air velocity.

However, the test cases need to be conducted for longer durations of time in order to evaluate the system performance accurately.

References

[1] http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=IN.
[2] A Hoshino, K Shinozaki, Y Ishisaki, T Mihara, Improved PID method of temperature control for adiabatic demagnetization refrigerators, Nuclear Instruments and Methods in Physics Research A 558 (2006) 536–541.
[3] Chin-An Hsuan, Rongshun Chen, Intelligent control of exit temperature in a gas- fuel can-type combustor, Engineering Applications of Artificial Intelligence 15 (2002) 391–400.
[4] British Standard BS 874:Part 3:Section 3.1:1987, British Standard Methods for Determining thermal insulating properties – Part 3. Tests for thermal transmittance and conductance – Section 3.1 Guarded hot-box method.
[5] British Standards BS EN ISO 8990:1996, Thermal insulation –Determination of steady state thermal transmission properties –Calibrated and guarded hot box.
[6] Ghosh A , Hyde J Trevor , Neogi S 2013, "Development and Performance Evaluation of a Virtual PID Controller for a Guarded Hot Box Test Facility for U-Value Measurement" International Journal Of Emerging Technology and Advanced Engineering, Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, p. 17-21.
[7] Ghosh A ,"Study on the Performance Characteristics and Identification of the Parametric Control Strategies of a Guarded Hot Box System and the Development of the Closed Loop Feedback Control Systems for U-Value Measurement" , M.Tech Thesis, May 2013.