İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

INVESTIGATION OF THERMOSTAT-SET CONTROL AS A NEW DIRECT LOAD CONTROL METHOD

M.Sc. Thesis by

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CONTENTS

ABBREVIATIONS

TSC	: Thermostat-Set Control
CLC	: Cyclic Load Control

LIST of TABLES

LIST of FIGURES

LIST of SYMBOLS

μ	: Mean Value
σ	: Standard Deviation
θ_s	: Temperature Set Value
Δ	: Dead Band of the Air Conditioner Thermostat
θ_g	: Temperature Gain of the Air Conditioner
τ	: Time Constant of the House
P	: Rating of the Air Conditioner
V	: Noise element

ÖZET

YENİ BİR DOĞRUDAN YÜK KONTROL YÖNTEMİ OLAN TERMOSTAT-AYAR YÖNTEMİNİN İNCELENMESİ

Elektrik enerjisi talebi her yıl artmaktadır. Mevcut elektrik enerjisi üretim kapasitesi bazen artan talebi karşılayamamaktadır. Bu problemin üstesinden gelmek için elektrik üretim şirketleri Talep Yönetimi uygulamaktadırlar. Talep Yönetimi; tanım olarak; yükün şiddetini ve yük eğrisinin şeklini değiştirmeyi sağlayacak şekilde müşterilerin elektrik enerjisi kullanımlarını etkileyecek planlama ve uygulama eylemleridir. Yük Kontrolü, bir Talep Yönetimi uygulamasıdır. Yük Kontrolünün tepe yükü azaltma, elektrik üreten şirketlerinin kazançlarının arttırılması ve müşterilerin rahatsızlığına sebebiyet vermeyi minimize etmek şeklinde birçok yönü vardır. Bu tez çalışmasında, müşteri rahatlığı temel kriter alınarak Yük Kontrolü konusunda çalışılmıştır. Bu yönde Termostat-Ayar yöntemi adlı yeni bir doğrudan yük kontrol yöntemi geliştirilmiş ve tepe yük azaltma ile müşteri rahatlığının sağlanması bakımından incelenmiştir. İlk olarak, kırk tane evden oluşan bir sistem matlab-simulink ile simule edilmiştir. Bu simülasyon, farklı dış sıcaklık değerleri için Yük Döngü kontrolü ve Termostat-Ayar uygulamaları için incelenmiştir. Bu çalışmadan sonra, C programlama dili ile Monte Carlo simülasyonu oluşturulmuştur. Bu, Monte Carlo simülasyonu ile toplam yükteki değişimler ve ev ısı histogramları incelenmiştir. Bu çalışmaların sonuçlarının değerlendirilmesi ile Termostat-Ayar yönteminin genel olarak müşteri rahatlığını temin etmekte etkin olduğu ve tepe yükü farkedilir ölçüde azalttığı sonucuna ulaşılmıştır.

SUMMARY

INVESTIGATION OF THERMOSTAT-SET CONTROL AS A NEW DIRECT LOAD CONTROL METHOD

The demand of electric energy increases every year. The current electric energy production sometimes fail to supply the increasing demand. To overcome this problem Demand Side Management is applied by the electric utilities. Demand Side Management is; by definition; the planning and implementation of those utility activities which are designed to influence customer use of electricity, in ways that will produce desired changes in the magnitude and shape of utility's load. Load Control is an application of Demand Side Management. Load Control has different aspects such as reducing peak demand, maximizing utility profits and minimizing discomfort caused to customers. Here in this thesis, Load Control due to the customer comfort satisfaction is taken under consideration. So in this way, a new direct load control method; 'Thermostat-Set Control' method; had been developped and investigated in the aspects of achieving a significant change in the peak of the load curve and maintaining endurable comfort levels for customers. First, a simulation of a system consisting of forty houses had been developped in matlab-simulink. This simulation had been studied for the cases of Cylic Load Control and Thermostat-Set Control for different ambient temperature values. After this study, Monte Carlo simulation had been developped with C programming language. The change of total power and the temperature histograms of the houses had been investigated with this Monte Carlo simulation. By observing the results of these studies, this developped new direct load control method, 'Thermostat-Set Control ' method, is found to be generally an effective method in maintaining the desired comfort level for customers besides reducing the peak power at a noticeable rate.

1. INTRODUCTION

The demand of electric energy increases every year. The current capacity of electric energy production sometimes fail to supply the increasing demand. To overcome this problem Demand Side Management is applied by the electric utilities. The subject focussed in this thesis, is Load Management which is an application of Demand Side Management. Load Management is classified as Direct Load Control and Indirect Load Control. Here, in this thesis a new Direct Load Control method is modeled and simulation programs are adapted to this model with two different programs, namely matlab simulink program and C programming language.

1.1 Demand Side Management

Demand Side Management is by definition, planning and implementation of the utility activities which are designed to influence customer use of electricity, in ways that will produce desired changes in the magnitude and shape of utility's load [2-4]. In Demand Side Management, loads with energy storage capabilities are preferred. Because these loads are immune to the short interruptions, without leading to significant decreases in the comfort level of customers. Energy storage capabilities of these loads enable them to be convenient for the interruptions. Interruption cause the peak load in the system to be reduced. Generally, in distribution systems, thermostatically-controlled loads are the ideal candidates for Direct Load Control applications for both the energy storage capabilities and large power consumption compared to other loads in a house.

1.2 Load Management

Load Management is an application of Demand Side Management. Load Management has different aspects such as reducing peak demand, maximazing utility profits and minimizing discomfort caused to customers. Load Management programs are being developped to help utilities use their generation facilities more efficiently. These systems will shift load to off-peak times or actually reduce the amount of electric energy required in peak load times. If the population of an area increases, for example this may happen when a new expressway is built to by-pass the city, in a primarily rural farm land. After this new change, density of accomodation in this region would increase. So, the load demand for this area will change significantly with these changes. An area that has previously had a very low density could change if the area is developped as single family dwelling units. The change would be more significant, if the area was developped for commercial and industrial purposes. Also energy use patterns change as technology changes. The way people heat and cool their homes and offices, will bring significant changes to the density of energy demand. If new products are developped that will increase the amount of energy required to do a certain task, this will mostly be spread quickly. As a result there would be an increase in the electricity power use. For example, the widespread use of air-conditioners has probably had the most significant impact on the electric energy consumption.

Load Management can be classified into two, namely Direct Load Control and Indirect Load Control. Direct Load Control is based on controlling the loads directly, by controlling from the center. However, Indirect Load Control includes the controlling of loads indirectly. For example, a deal is signed between the customer and the electric utility, which the utility offers customers different choices of load control programs. Customers choose the most appreciate load control program for themselves. These different choices may be %30 interruption of consumed power for the hour 10.00 am, %50 interruption of consumed power for the hour 12.00 am or %60 interruption of consumed power for the hour 14.00 am.

Individual loads in distribution systems can be categorized into two different groups thermostatically-controlled and manually-controlled. Thermostatically-controlled devices provide the largest contribution to the total load in a typical house whereas manually-controlled loads are switched on and off by occupants of the house in undetermined fashion. The lifestyle of the occupants of the house has a significant influence on the contribution of these loads to the total load of the house.
In Direct Load Control, thermostatically controlled loads; which are also may be named as loads with energy storage capabilities; are preferred. Because these loads can be interrupted for some duration to reduce the peak in the system, without

causing any significant decrease in the comfort level of customers. Load Control is applied by making use of thermic energy storage capabilities of these loads . These loads are namely, air- conditioners, water heaters, heat pumps, etc. Mostly, for Direct Load Control applications, air-conditioners and heaters are used [1].

Thermostatically controlled loads are square wave type of loads. There are many studies on modelling these types of loads. Prediction of the Direct Load Control actions is important before applying the actions on the real system. So it is important to create the models for the loads because the models enable us to estimate the possible effects, before the control is applied on a real system. So the load model that is developped for the Direct Load Control, is highly expected to reliably reflect control effects. Load models which are based on statistical analysis of historical data can not reliably give the accurate results of predicting the aggregated load as the result of the Direct Load Control actions. But there are physically-based load models, these can accurately reflect the effects of Direct Load Control on the system. Another feature of phsically-based load models is that, the effect of model parameters on the total load can evidently be seen. There are many studies on modelling the loads with statistically-data based models and with physically-based models [5-11].

1.3 Literature Review on Direct and Indirect Load Control

There are many studies on Direct Load Control [12-17]. One of the successful studies on application of Direct Load Control in distribution systems, had been done by South California Edison company [18]. In this study, the peak in the system had been reduced by controlling 100,000 air-conditioner from the center, by offering %50, %67, %100 control alternatives to the customers. The consumer air conditioners were interrupted in groups at different times, for a while. This study is a good example of a Direct Load Control program.

Another study on Direct Load Control using stochastic difference equation model had been done by C. Uçak [19]. Uçak had searched the Direct Load Control effects by using a physically-based load model. In this study, changes in the total load under different control cases had been observed with the statistical changes of the house's temperature values after controlling of the customer loads. It had been concluded that the peak load is reduced by directly controlling the air-conditioner loads in the system while an increase had been observed at the house temperature values.

A study on the effectiveness of Direct Load Control application had been made by C. Uçak and R. Çağlar [20]. They had examined the claim, that the effectiveness of Direct Load Control application is based on system parameters. In their study, a stochastic difference equation; which is a physically-based load model; had been used. This model had been used to study the effects of load parameters and the direct load control actions.

Another work on searching for the optimal Direct Load Control method, taking the basis of customer satisfaction and utility benefits, by using fuzzy logic approach, had been made by Bhattacharyya and Crow [21].

A significant study, based on customer's preferences had been made by McKenna [22]. In this work, application of consumer tools to the measurement of consumer preferences for Load Management service options had been observed. It had been aimed to get an understanding of the preferences of customers for leading planners designing better Load Management programs that meet the needs of customers, while being consistent with the utility's cost and capability to deliver. The author had noted that an answer to a question "how valid are results of your analysis?" is critical to prove the strenght of the basic thesis of this study. However, most studies are made under commercial aspects and hence are not published. The studies that have been published, however show high predictive validity, and claimed that this study had also been streghtened by the author's ten years of experience with these procedures. A theorical study on customer preferences has been made by Sanghvi, Levy and Wharton [23]. In this study, a customer preference based approach had been searched for planning Demand Side Management programs. A concept of perceived value of electric service to customers had been introduced and defined broadly, which can be summarized as, a concept that reflects the relative value a consumer thinks he/she derives from using it in comparison to other goods or services. It had been claimed that the perceived value concept and customer preference approach needs to be transformed from concept into useful tools for utility planning and resource evaluation.

A study on Indirect Load Control, had aimed to search how customers' habits alter after the pricing of energy program due to usage times of the day in Denmark [24]. In the study, multi-rate time-of-day tariffs had been introduced in two categories namely, level B (for large customers) and level C (for other customers).

The load control equipment which can be attached to the tariff units of the power company had been delivered to the customers by the power companies. The total Load Management project had been divided into three sub-projects; first one is the development of tariff equipment and load control equipment; second one is a demonstration project including an investigation of customer behaviour; and the third one is development project of bidirectional communication over the power distribution network. The second main element of the project had been an investigation of customer behaviour, where the customers' reaction to the multi-rate time-of tariff had been examined. The study had been composed of 500 customers, and lasted 1,5 years. At the end of the investigation, it had been observed that the customers had changed their behaviour. The results of the investigation had been evaluated from the distribution of consumed electricity at different tariff levels and partly from the load curves registered. Although besides the attempts based on interviews with the customers, the results for the group of industrial and commercial customers are not statistically significant.

Another study aiming to observe the principles of getting significant changes on the system load curves, had been made by Nordell [25]. For achieving an effective Load Management, those important principles had been observed; first one is claimed that energy consumption must be reduced at the utility's peak times, not only based on individual demand; second one is load cycling methods' duty factor has to be smaller than the natural duty factors; third one is Load Management has to be applied to controllable loads; and the fourth one is, for preventing adverse impact on the utility system attention has to be paid on the recovery characteristics of the controlled loads.

1.4 Objective of The Thesis

For electric utilities, it is crucial to supply reliable energy to customer units. This attitude deeply hides the attention towards the concept of customer satisfaction. In the past for load control applications, customer satisfaction was not a basic criterion. But today the competition between the electricity suppliers is tough, so they have to pay attention to their customer's demands. In this thesis, a new direct load control method, Thermostat- Set Control method, which pays attention to concept of customer satisfaction had been investigated. This method is based on the aspects of achieving a significant change in the peak of the load curve and maintaining endurable comfort levels for customers.

1.5 Mathematical Model of The Developped New Direct Load Control Method

Load Control has different aspects such as reducing peak demand, maximazing utility profits and minimizing discomfort caused to customers. In this thesis Load Control method called Thermostat-Set control is studied based on the customer comfort. This method is developped to achieve a significant change in the peak of the load curve and to maintain endurable comfort levels for customers.

In Demand-Side Management, loads with energy storage capabilities are preferred. Load Management is applied by making use of thermic energy storage capabilities of these loads that are air-conditioners, water heaters, heat pumps, etc. Mostly for Direct Load Control applications, air-conditioners and heaters are used. In Direct Load Control it is important to estimate the effects before control is applied on a real system. Thus, the load model is expected to reflect the dynamic of loads when Direct Load Control is applied. Load models that are based on statistical analysis of historical data can not reliably give the accurate results. But, there are physically based load models which accurately reflect the effects of Direct Load Control actions on the system.

In this thesis, Thermostat-Set Control method, a new Direct Load Control application based on house temperature value will be studied. This control method will be compared with the commonly used Load Cycling method aiming to decide on the success of the Thermostat-Set Control method. Thermostat-Set Control is based on the house temperature values which are the basic criteria for the customers' comfort level. In the past customer comfort level wasn't the objective of the load control applications. But today, the tough competition between the electricity supplier companies lead them to take intense care of their customers' satisfaction.

1.5.1 Dynamic Of An Air –Conditioner

In reference [22], a model for the temperature of a house having an air conditioner had been given by presenting the discussion developed by Ihara & Schweppe [26]. This model is given by:

$$\frac{d\theta(t)}{dt} = -(1/\tau).[\theta(t)-\theta_a+w(t)\theta_g] \qquad (1.1)$$

Here the parameters are as follows; $\theta(t)$ (^{o}C) is the inside temperature of the house, θ_a(^{o}C) is the ambient temperature, θ_g(^{o}C) is the temperature gain of air conditioner, and τ (hr) is the time constant of the house. The variable w(t) is a binary variable denoting the state of the air-conditioner; Off=0 and On=1. The state changes when the temperature of the house reaches the thermostat upper or lower limits, given by $\theta_s+\Delta/2$ and $\theta_s-\Delta/2$ respectively. When the inside temperature of the house reaches these limits; $\theta_s+\Delta/2$ and $\theta_s-\Delta/2$; air-conditioner state changes from zero to one,and when the lower limit is reached, the state changes from one to zero. Figure 1.1 shows the state of thermostat and the house temperature as a function of time when the ambient temperature is constant, that is called during steady state.

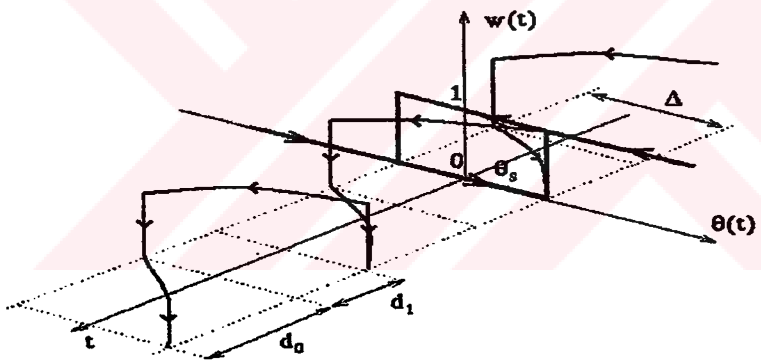

Figure 1.1. The state of thermostat and house temperature as a function of time during steady state

The time constant of the house can be written as the product of the thermal capacity C (kWh/^{o}C) and the thermal resistance R (^{o}C/kW) of the house.Also the temperature gain of the heater can be written as the product of the rating of the air conditioner P (kW) and the thermal resistance R of the house. Therefore, the above equation can be written as

$$\frac{d\theta(t)}{dt} = -\frac{1}{CR}.[\theta(t)-\theta_a+w(t)RP] \qquad (1.2)$$

In this equation, C and R parameters are the house coefficients related to the insulation level, volume, walls, surface etc. Thermal capacity and thermal resistance of the house in general depend on each other. For example, if the thermal resistance of the house is increased by the thickening of the walls then the thermal capacitance of the house will also change. But the change may be small. In the reference [20] C and R had been considered to be independent parameters. P is related to the air-conditioner device installed in the house and will change according to the size of the device. C, R, and P can be considered constant for a house and may change from house to house depending on the structural design and the air-conditioner size.

1.5.2 Stochastic Difference Equation Model

In [20], a load model based on stochastic difference equation had been used to study the effects of direct load control actions. C. Uçak and R. Çağlar had presented the disscussion of the stochastic difference equation, which had been given by R.E. Mortensen and K.P. Haggerty [7]. The significant difference of stochastic difference equation load model from the other types of load models is that the stochastic difference equation model is suitable for the computer analysis. The assumption is that the thermostat always switches exactly at sampling instants. Time, t, is discretized by using a sampling period h. With the notation $a= e^{-h/\tau}$ as in reference [7] or $a=e^{-h/CR}$ the difference equation for air-conditioner load will be

$$\theta[(n+1)h] = a\theta(nh) + (1-a)[\theta_a - w(nh)\theta_g] \qquad (1.3)$$

The stochastic difference equation can be obtained by including the effect of random influences in the environment. This can be done by adding a discrete white noise term V(nh) to equation (1.3). The result is:

$$\theta[(n+1)h] = a\theta(nh) + (1-a)[\theta_a - w(nh)\theta_g] + V(nh) \qquad (1.4)$$

Here V(nh) is a Gaussian white noise discrete time process with zero mean. The variance will depend on the noise input from the environment. Direct Load Control actions can be incorporated to equation (1.4). For this, a control term c(nh) which can only take a binary value is multiplied with the heat gain of the air-conditioner.

By replacing θ_g with RP, the stochastic difference equation will take the form

$$\theta[(n+1)h] = a\theta(nh) + (1\text{-}a)[\theta_a - c(nh).w(nh).RP] + V(nh) \qquad (1.5)$$

Here c(nh) term represents the signal sent to the air conditioner either to run or to stop. If the signal is 0 for a certain period then the air conditioner will be off for that period. The signal will be 1 if the air conditioner does not participate in the Direct Load Control cycle, that is, the air conditioner will be in natural diversity.

2. MATLAB SIMULATION OF THERMOSTAT-SET CONTROL METHOD AND LOAD CYCLING METHOD

A New Direct Load Control Method that is called Thermostat-Set Control method and commonly used Load Control method called Cyclic Control method had been investigated. The model of the new Direct Load Control method had been developped and the validity of the method had been measured by the simulation developped with matlab simulink. Matlab simulations are developped starting with the load model of one consumer unit. Simulations include forty consumer units that are groupped in four. All the houses in the simulation have different parameters such as different consumer unit characteristics, different thermostat set values, power gain, white noise, time constant values. This diversity had been preferred because it reflects the real distribution system closely. Each of different parameter values of the consumer units' are determined by gauss-random generator by using the mean and standard deviation values given in Table 2.1. Other parameters which stand for the white noise term in the load model of each unit namely, noise and noisesample, have the numeric values of 0.002 and 0.02 respectively for each of the forty consumer units. Another parameter for the white noise term is the seed, which controls the random noise production by the noise term in matlab simulink environment. This parameter is different for each house for appointing forty different white noise effects.

Table 2.1 The Characteristic Values For Consumer Units

PARAMETER NAME	μ	σ
θ_s	20 ^{o}C	2.0
Δ	2 ^{o}C	0.3
θ_g	40 ^{o}C	5.0
τ	3 hours	0.5
P	2 kW	0.2

2.1 Thermodynamic Model of One Consumer Unit

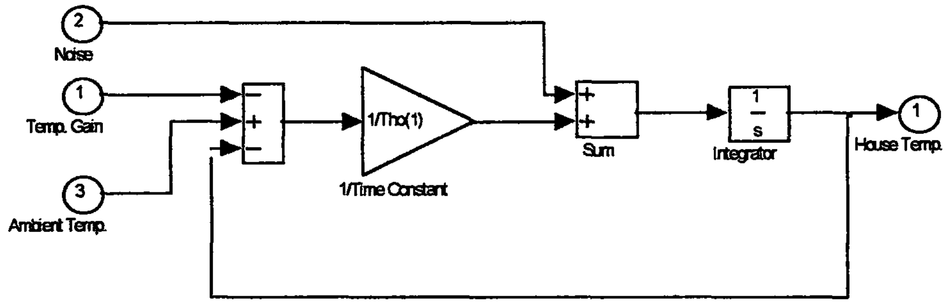

Figure 2.1 Thermodynamic model of one consumer unit

Thermodynamic model of one consumer unit is given in Figure 2.1. The model is developped upon the laplace transformation of the Equation 2.1. This model has three input and one output port. Output port is House Temperature, which gives the change of temperature in time whereas, input ports are Gain, White noise and Ambient temperature. Gain is different for each of the consumer unit derived with the gauss random function with the given mean and standard deviation values in Table 2.1. This thermodynamic model of one consumer unit is a part of the block called House Temperature Dynamic, which is shown in Figure 2.2.

2.2 Model of One House

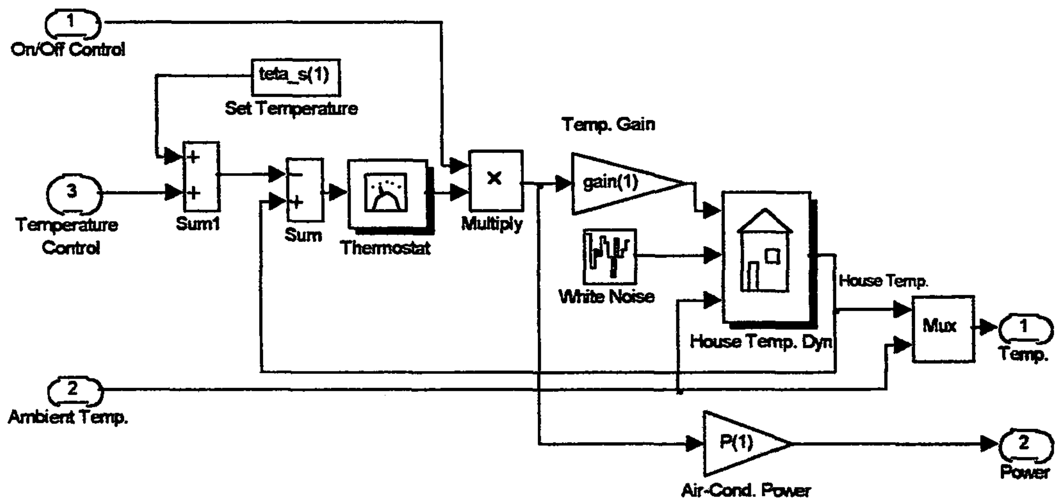

Figure 2.2 Matlab Simulation Model of One House

The Matlab Simulation model of one house that is shown in Figure2.2, has three input and two output ports. Input ports are namely On/Off Control (Load cycling method's application), Temperature Control (Thermostat-set control application) and Ambient temperature. Ambient temperatute data is delivered to the related port with its two of components namely, Average Ambient Temperature and Daily Temperature Change. Average temperature data is entered to the Average Ambient Temperature block. Daily Temperature Change block is for the changes in temperature at different hours of a day. For example daily temperature increases in the morning in summer season. Then temperature increases as hours passing towards 12.00 am., generally temperature reaches its maximum value at around 12.30 am. the attitude of temperature in a summer daytime is as explained; after 14.00 am. temperature tends to decrease, and reaches its minimum value around 12.00 pm. This change of daily temperature is modelled with the Daily Temperature Change block which produces sine wave with adjustable parameters; amplitude, frequency (rad/sec), phase (rad) and sample time. The ambient temperature data entered to the related port is derived with summation of those two block's inputs; in other words, addition of the sine wave's change and average temperature data gives the final ambient temperature input. Besides the input ports, each house has two output ports called, Total Power and Temperature Change. Temperature Change is the data of the change in house temperature and the ambient temperature change in time. The block Mux combines two different data in one graph, so it is possible to view both graphics in one window. Total Power output data is the change of power consumed by the houses as a function of time.

White noise block stands for the small disturbances such as openning or closing of doors or windows that have effects on the inside temperature of each of consumer units. This block produces different values of white noise element for each of the consumer units, with its parameter namely seed, that is responsible for the production of characteristic white noise term for each of the block. Seed parameter is different for each house in the simulation to accomplish different white noise elements in each consumer unit.

2.3 Appplication of Load Cycling Method in The Matlab Simulation

Load Cycling Method is a commonly used Direct Load Control method. The main objective of this method is reducing the usage of electric power by the consumers at peak hours. The application of the method is reflected to the simulation model with the control block named, Cyclic Control as seen in Figure2.3. This block is a pulse generator, producing pulses with the required parameters; period (sec), duty cycle (% of period), amplitude and start time. Produced pulses are with the given amplitude value, repeating itself with the given duty cycle in the determined period (sec). The start time is the indicator of beginning instant of the generated pulse. With this developped program in matlab-simulink, it is possible to control the consumer units group by group. To explain the concept of controlling the electric power consumption of houses in groups; let's propose that all groups are controlled for 15 minutes per hour. Phase shift between each group is derived with the timing of control. In other words when the control period is over for the first group, it is time for the second group to be controlled, and this whole chain repeats itself throughout all other groups.

2.4 Thermostat-Set Control Simulation in Matlab

Thermostat-set control is applied to the simulated consumer groups using Central Temperature Control Block, which the block is seen in Figure 2.4. This method is based on the comfort level of customers. Due to this basis, thermostat set temperature of each consumer unit is controlled from the center. This is the flexibility of this Direct Load Control method as the control is accomplished from the center, easy to manipulate at any time as well. Temperature is controlled from the center by the central temperature control block in the simulation. The control block can be seen in Figure 2.4. Central temperature control block is connected to the Temperature Control port of four of the groups.

The main objective of the Thermostat-Set Control method is to reduce power used by the air conditioner loads while inside temperature of each of the consumer unit are kept around tolerable values. These tolerable values are determined due to consumers comfort demands. This control is accomplished by increasing temperature value in the Central Temperature Control block that is connected to the

Temperature Control port of each group. Increasing the temperature set value is the basis of this method. Various conditions of Load Cycling method and Thermostat Set Control method can easily be applied to the system. Under these conditions change of power in time, which is consumed by the consumer units, can be observed. The results of these various control states may be used for comparison between two of of the methods the methods applied.

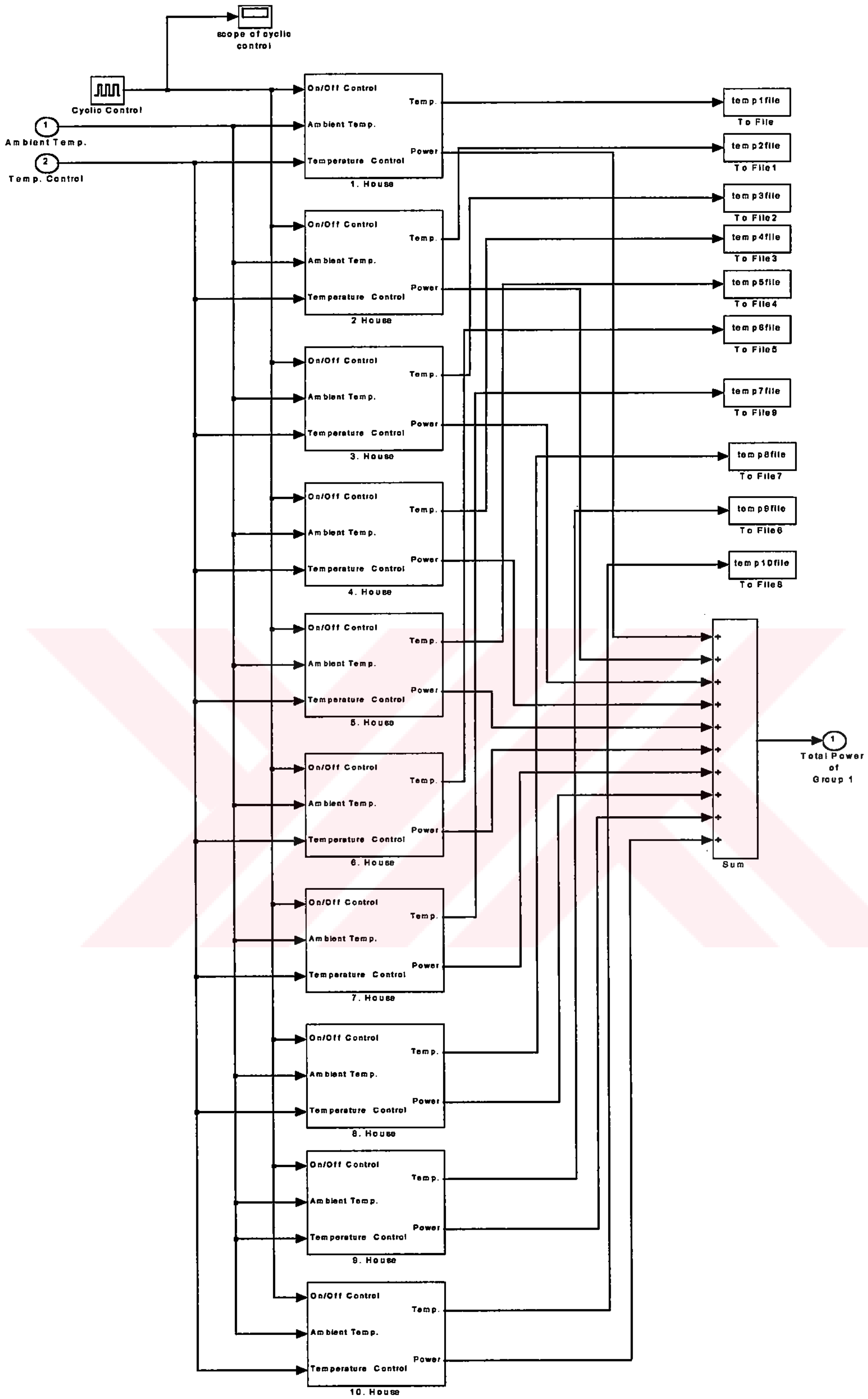

Figure 2.3 Matlab Simulation Model of One Group Consisting of Ten Houses

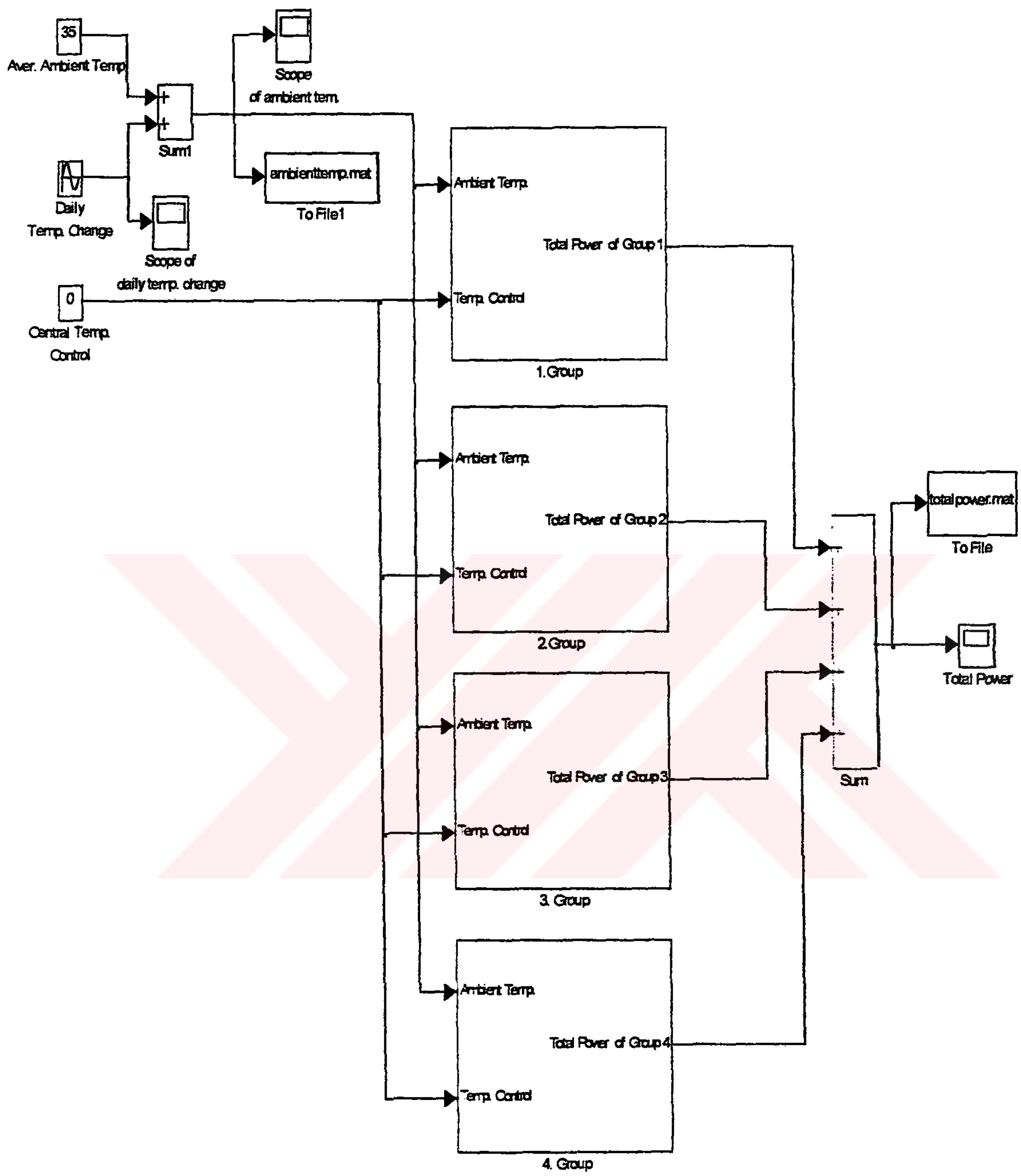

Figure 2.4 Matlab Simulation Model of Forty Consumer Units in Four Groups

3. ANALYSIS OF CONTROL METHODS IN MATLAB

The matlab simulation is a system consisting forty consumer units with different thermal characteristics in an environment with one ambient temperature data common for all houses. In this system two of load control methods are analyzed and compared. The results of the simulations are the temperature distributions and total power change of the houses in time for the system.

3.1 Maximum Temperature Histogram of Forty Consumer Units

Maximum Temperature Histogram of the consumer units show us the distribution of the houses according to their maximum temperature values for the stated conditions. Each consumer unit in the simulated system has an output of inside temperature change in a daytime. The plotting of this output is the temperature change of the considered house in 24 hours. The maximum temperature value of each consumer unit is found by using matlab function 'max'. After this application, maximum temperature value of all the houses in the simulated system are plotted in the histogram graph . Eight different conditions of sytem are simulated that are shown in Figure A.9, A.10, A.11, A.12, A.13, A.14, A.15, A.16 in Appendice A.

3.1.1 Comparison of Maximum Temperature Histogram of Forty Houses When the Ambient Temperatures are $30^{o}C$ and $40^{o}C$ For No Load Control

In Figure A.1and Figure A.2 maximum temperature histogram of the houses in the system under conditions of $30^{o}C$ and $40^{o}C$ without control have been given respectively. These both cases have one condition in common that's, there is no control method applied to the system. Because the thermostat set values of the consumer units are the same for simulations under the different conditions, the ambient temperature difference by $10^{o}C$ between these given ambient temperature values would only lead the total power consumption of the system to incerase and the histograms are expected to be similar. The increase is a result of the reaction of the system to sustain the houses' thermostat set temperature values. So the maximum temperature histogram of the consumer units would be similar. This is seen from the Figure A.1 and Figure A.2 as well. The mean value of these distributions are almost the same as seen from the figures. The overall distribution of the houses is our point to be keen on, so it is observed that the stacks of the bars are concentrated around almost 22^{o} C in both figures. This shows that the houses in both cases are almost in same conditions, namely having similar inside temperature values.

3.1.2 Comparison of Maximum Temperature Histogram of Forty Houses When the Ambient Temperatures are 30^{o} C and 40^{o} C For %25 Cyclic Load Control and For No Load Control

In Figure A.3 and Figure A.4 maximum temperature histogram of the houses in the system under conditions of 30^{o} C and 40^{o} C ambient temperatures with applied %25 cyclic load control have been given respectively. These two cases are examples of %25 cyclic control applications, with outputs of maximum temperature histograms. FigureA.1 and FigureA.2 are the graphs for the case of without any control applied to the system. For the comparison of these groups with control and without control, it is predicted that the cyclic load control would lead the system to face higher temperature values than the one without any control applied. This prediction is logical because as the duty period of the air conditioners are lowered by the percentage of 25, the cooling period of the consumer units are shortened in time by a rate with this attempt. The figures all support this prediction. It is seen that control attempt brought higher temperature than the case without any control applied. This result is normal and a natural response of the system. The distribution in these histograms is to be observed to examine the result that has been mentioned above. The distribution of the case of load control seems to be shifted to right handside with respect to the case with no load control. These two figures are the compared because they are related that one stands for case with control and the other having the same conditions but without control. The changes may be thought to be very small, but the response of the system is reliable for this small scaled system composed of forty consumer units.

3.1.3 Comparison of Maximum Temperature Histogram of Forty Houses for the Cases of 2^oC and 4^oC with the cases of No Load Control

In Figure A.5 and Figure A.6 maximum temperature histogram of the houses in the system under conditions of 30^oC and 40^oC ambient temperatures with 2^oC Thermostat-Set Control have been given respectively. Also, in Figure A.7 and Figure A.8 maximum temperature histogram of the houses in the system under conditions of previously stated ambient temperatures with 4^oC Thermostat-Set Control have been given. Basically, these temperature-set control applications would result in inside temperature rise in consumer units. Anyway, the distribution in these histograms prove this rise of temperature value in consumer units. For example the mean value of the distribution in Figure A.1 is aproximately 22^o C whereas it is around 24^o C in FigureA.5. Also the distribution in Figure A.2 is shifted nearly 2^o C to right handside than the temperature histogram graph in Figure A.6. These supportive observations are pointers of the forward settling of the distributions in these figures. This nearly 2^oC forward settlement is normally the expected response of the system due to the temperature-set control applied. With the same approach we may consider the distribution settlement in FigureA.7 and FigureA.8 compared with the first two figures namely, FigureA.1 and FigureA2. The approximate mean value of the distribution in FigureA.1 and FigureA.2 are $21{,}5^oC$ and $23{,}5^oC$ respectively, whereas the same values in FgureA.7 and FigureA.8 are approximately 25^oC and 26^oC respectively. These observations show that Thermostat-Set Control has almost direct effect on customers' comfort, as control by 4^oC brought bigger temperature increment in inside temperature of houses' than the control by 2^oC.

3.2 Minimum Temperature Histogram of Forty Consumer Units

Minimum Temperature Histogram of consumer units show us the distribution of the houses due to their minimum temperature values for the stated conditions . Each consumer unit in the simulated system has an output of inside temperature change in a daytime. The plotting of this output is the temperature change of the considered house in a daytime with 24 hours.

The minimum temperature value of each consumer unit are found by the application of a matlab function namely 'min', to temperature change output of each consumer unit. Eight different conditions of sytem are simulated that are shown in FigureA.9, A.10, A.11, A.12, A.13, A.14, A.15, A.16 in Appendice A.

3.2.1 Comparison of Minimum Temperature Histogram of Forty Houses When The Ambient Temperatures are 30^{o}C and 40^{o}C For %25 Cyclic Load Control and For No Load Control

Minimum temperature histogram of forty houses in the simulated system under conditions of 30^{o}C and 40^{o}C without control and with %25 cyclic control are given in FigureA.9, A.10, A.11, A.12 respectively. The cyclic control is expected to bring temperature increases to the consumers, that the minimum temperature histograms are also expected to have forward settlement towards higher temperature values. The mean value of Figure A.9 is approximately 19^{o}C whereas the same parameter for Figure A.11 is nearly 20^{o}C. These observations show the existance of forward settling of distribution for given conditions. The same forward settling is seen in Figure A.12 with respect to Figure A.10.

3.2.2 Comparison of Minimum Temperature Histogram of Forty Houses for the Cases of 2^{o}C and 4^{o}C with the cases of No Load Control

Minimum temperature histograms of the houses in the simulated system under conditions of 30^{o}C and 40^{o}C ambient temperature values with cyclic control by 2^{o}C and 4^{o}C are given in Figure A.13, A.14, A.15, A.16 respectively. To observe the changes in the distribution of these four figures compared with the Figure A.9 and Figure A.10, it is proper to observe the approximate mean values of these graphs. The approximate mean value is 19,5^{o}C in FigureA.9, 21.5^{o}C in FigureA.13 and 24^{o}C in FigureA.15. The mean values that are approximately determined from the graphs, point that the distribution of the minimum temperature histogram settles towards higher temperature values as the temperature-set control is strenghtened by higher degrees of control applied. The control by 2^{o}C lead the ditsribution in small scale than the control by 4^{o}C as it is the normal, expected response of the simulated system. The distribution of the minimum temperature histogram in Figure A.10, A.14, A.16 also settles forward as the Thermostat - Set Control is applied by $2^{o}C$ and $4^{o}C$ to the simulated system. If we observe the approximate mean values of the considered minimum temperature histograms, they can be approximately determined as $19{,}5^{o}C$ in FigureA.10, $22^{o}C$ in FigureA.14 and $24^{o}C$ in FigureA.16. These are evidently pointing the forward settlement of the distributions in these histograms.

3.3 Average Temperature Histogram of Forty Consumer Units

Average Temperature Histogram of consumer units show us the distribution of the houses due to their average temperature values for the stated conditions varying with the ambient temperature values and control cases. Each consumer unit in the simulated system has an output of inside temperature change in a daytime. When this output is plotted, temperature change in a daytime is derived. The average temperature of each consumer unit is found by a matlab function 'mean', by applying to temperature output of the houses in the considered system. Eight different conditions of sytem are simulated that are shown in Figure A.17, A.18, A.19, A.20, A.21, A.22, A.23, A.24 in Appendice1.

3.3.1 Comparison of Average Temperature Histogram of Forty Houses When the Ambient Temperatures are $30^{o}C$ and $40^{o}C$ For %25 Cyclic Load Control and For No Load Control

In Figure A.17, A.18, A.19, A.20 average temperature histogram of the houses in the system under condition of $30^{o}C$ and $40^{o}C$ ambient temperatures without control and with applied %25 cyclic load control are given. As it had been observed before for the maximum and minimum temperature histogram graphs to settle forward with the applied Cyclic Control and Thermostat-Set Control. So, the average temperature histograms are expected to response the same way. The approximate mean value for Figure A.17 is smaller in quantity than for the Figure A.19. Also the distribution in Figure A.20 is at the right handside with respect to the distribution seen in Figure A.18. The increment in the inside temperature value in the houses is small, but the tendency of the system response to the cyclic control is as expected.

3.3.2 Comparison of Minimum Temperature Histogram of Forty Houses for the Cases of 2^oC and 4^oC with the cases of No Load Control

Average Temperature Histograms of the houses in the simulated system under conditions of 30^oC and 40^oC ambient temperatures with cyclic control by 2^oC and 4^oC are given in Figure A.21, A.22, A.23, A.24. Basically these temperature-set control applications would lead the simulated system to reach higher average inside temperature values, as it had been the same for the maximum and the minimum temperature values. Distribution in these histograms prove the average temperature rise in consumer units as seen from the figures. The mean value of the distribution in Figure A.17 is nearly 20^oC whereas it is approximately 22^oC in Figure A.21. This forward settlement towards the higher temperature values can be observed in Figure A.22 with respect to the Figure A.18. In Figure A.23 the approximate mean value can be observed as 24^oC. In Figure A.24 the mean value of the distribution is about 25^oC whereas it is nearly 21^oC in Figure A.18. These results are indicating the settlement of the distribution forward in the considered graphs that especially the temperature-set control by 4^oC had lead the simulated system to face higher average temperature values. These evident results are pointing the importance of the temperature-set control by the customers' point of view, that the maximum temperature determined as tolerable by consumers, this tolerable value would not be unexpected as customers determine its value.

3.4 Analysis of Total Power Graphs of the simulated system for various conditions

In Figure A.25 and Figure A.26 change of total power consumed by the simulated houses for the cases of ambient temperature 30^oC and 40^oC without control are given, respectively. The total power is changing approximately between 5-35 kW in Figure A.25. The graph has fair sharp peaks having minimum nearly at 5kW and maximum at about 35kW. In Figure A.26, total power changes between 20-55kW approximately, having maximum peak at around 60kW. The total power seen in FigureA.26 is higher than the total power for the condition of 30^oC ambient temperature in Figure A.25. This result is expected because air conditioners would work harder in an ambient temperature with $40^o C$ than in a case with $30^o C$. This response normally repeats in the cases with Cyclic Load Control and Thermostat-Set Control applications. In Figure A.27 and Figure A.28 total power change for the condition of %25 cyclic control applied to the system had been given. In Figure A.29, A.30, A.31, A.32 change of total power consumed by the houses in the system for the conditions with temperature-set control by $2^o C$ and $4^o C$ had been given. It can be observed in Figure A.29 and Figure A.31 that the consumed power had a decrease getting dense in smaller interval, numerically between 15-20kW and 10-20Kw respectively. Same response had been observed in Figure A.30 and Figure A.32 that total power consumed is lowered as targetted with these control applications. These changes, the lowering of total power consumed for the considered cases are not sharply significant, but this is normally expected for the scale of this simulated system.

4. MONTE CARLO SIMULATION FOR THERMOSTAT-SET CONTROL AND CYCLIC CONTROL METHODS

Monte Carlo simulation of the two load control methods, Thermostat-Set Control method and Cyclic Control method is done with the developped program. The program is written in C programming language as this programming language is flexible and powerful for large scaled programming.

The purpose for writing a second program for the simulation of the two load control methods is, the need for analyzing a large scaled system. The simulation program developped with matlab simulink is the simulation of a small scaled system composing of 40 consumer units, and increasing the number of units in matlab does not allow an efficient simulation. The load control methods applied to that scaled system may not reflect the general behavior of the system, but to understand the system's behavior, a larger scaled system is needed to be simulated. So, besides analyzing the system response with matlab simulation program for the cases of Thermostat-Set Control and Cyclic Control method, a new simulation program had been developped.

This C program is designed for both of the load control methods, the Thermostat-Set Control and Cyclic Load Control methods. The program is run for 10 000 consumer unit system. The system is simulated for various control conditions as it would be stated in the following part, for observing the effectiviness of the Thermostat-Set Control method.

The main objective of developping this program is, to analyze the behavior of the system upon the different cases of load control applications. Monte Carlo Simulation program had been run for Thermostat-Set Control and Cyclic Load Control for the stated cases as being explained as follows.

The program has input files read before the program starts to run. These files are independent from the program's source code that this enables the user's to make changes without changing the code of the Monte Carlo Simulation program. One of these files has the parameter values of the simulated model of each consumer unit, with mean and variance values as shown in Table 4.1. Other input files contain ambient temperature files contain ambient temperature data, group number data and cycle times files contain ambient temperature data, group number data and cycle times for the Cylic Load Control application. The model for each consumer unit is, as explained in the Part 1.5.2 Stochastic Difference Equation on page 9, is the Equation 1.4. In this mathematical model the parameter θ, is the instantaneous temperature; where θ_a and θ_g are the parameters for ambient temperature and the temperature gain of the air conditioners respectively. The other parameter h is the sampling period, while a= $e^{-h/\tau}$.

Table 4.1 Parameter Values for Stochastic Difference Equation Model used in Monte Carlo Simulation

PARAMETER NAMES	μ	σ
V	$0\ ^{o}C/min$	0.1
θ_s	$20^{o}C$	1.41
θ_g	$20^{o}C$	6.00
Δ	$2^{o}C$	0.3
τ	120 min	20

4.1 Analysis of Normalized Air Conditioner Load Change in Time For Given Conditions of Cyclic Load Control

The change of Normalized Air Conditioner Load in time For Cylic Load Control had been given in Figure B.1 in appendice B. This figure shows the change of load for 15 and 20 minute Cyclic Load Control as well as for no load control between the hours 11.00-23.00. To understand Cylic Load Control for 15 minutes, the houses in the simulated system are gropped in four groups, and each group is interrupted for 15 minutes while the other three groups are in normal case, consuming electricity without any interruption or control. The control for 20 minutes are in the same way as well. All these cases are plotted on the same graph as seen in Figure B.1 to understand the advantage of the control actions with respect to each other and also with respect to no control case. As seen from the figure, Cylic Load Control had a significant effect on reducing the normalized load. The 20 minute load control has a lower mean value than the 15 minute control case, but the peaks although with very small quantities are sharper in 20 minute control than 15 minute control as can be observed from the figure.

4.2 Analysis of Normalized Air Conditioner Load Change in Time For Given Conditions of Thermostat - Set Control and The Temperature Histograms For The Related Control Cases

The change of Normalized Air Conditioner Load in time for 1^{o}C, 2^{o}C, 3^{o}C, 4^{o}C and 5 ^{o}C Thermostat-Set Control in 24 hours time as well as No Load Control cases are given in Figure B.2. This figure shows the significant effect of Thermostat-Set Control on reducing the normalized load. The Thermostat-Set control for 1^{o}C is less powerful than the case for 2^{o}C as it is expected. The behaviour of the system can be observed as, the degree of the Thermostat-Set control has direct effect on the reduction get in normalized load. The 5^{o}C Thermostat-Set control has the most powerful reduction in normalized load as observed. Anyway, this success of reduction in normalized load had another point to be keen on that, the inside temperature of the houses of course increase as the degree of Thermostat - Set control application increases. The temperature histograms for these control cases are given in Figure B.4, B.5, B.6, B.7, B.8, B.9, B.10, B.11 and B.12 with the Average, Median and Standard Deviation quantities of the distributions.

The change of Normalized Air Conditioner Load in time for 1^{o}C, 2^{o}C, 3^{o}C, 4^{o}C and 5^{o}C Thermostat-Set Control between the hours 11.00-23.00 as well as No Load Control cases are given in Figure B.3. The reduction of normalized load can be observed from the figure, but there is a negative case seen in the figure. This negative case is the peak formed at the end of the control application. As soon as the control is over, the normalized load becomes the maximum; that this leads the peak demand of power. This negative case can not be approved, more studies must be made to improve this new direct load control method to get the desired results. The solution to this problem can be the act of groupping the houses in the controlled sytem, that the peak would be lower. The magnitude of the peak power depends on the electricity consumption capacity of the houses basicly, so as the groupping would lower the number of interrupted houses in certain intervals of time, the reaction; like payback; of the houses in the groups after the interruption of energy, would be lower than the reaction of the interruption of all houses as we have seen in Figure B.3.

4.3 Comparison of the Normalized Air Conditioner Load Change in Time For Cylic Load Control and For Thermostat-Set Control

The change of Normalized Air Conditioner Load in Time for 15 min Cylic Load Control, 2^{o} C, 3^{o} C, and 4^{o} C Thermostat-Set Control and No Load Control case in Figure B.13. This figure enables us to observe the control methods by making use of comparison. Cylic Control has a significant effect on reducing the normalized load whereas Thermostat-Set Control for 2 ^{o} C and 3^{o} C are behind in getting the same success with Cylic Load Control. But Thermostat-Set Control method by 4^{o} C has the same scale reduction of normalized load with Cyclic Load Control, so to investigate if Thermostat-Set Control method is advantageous with respect to Cyclic Load Control, temperature histogram of all houses in the system for those control cases must be taken under consideration. In Figure B.14 this temperature histogram graph is shown for 15 minute Cylic Load Control 2^{o} C, 3^{o} C and 4^{o} C Thermostat-Set Control and No Load Control cases. To compare 15 minute Cylic Load Control case and 4^{o} C Thermostat-Set Control case, it is observed that the peak magnitude of the temperature histogram for CLC is lower than the case for TSC by 4^{o} C. But the distribution of the graph of CLC is wider than the one for TSC. This is not a good situation, because as the graph is wider with large standard deviation value, the number of houses having higher temperature value would be high. For about 17,5^{o} C-26^{o} C Cylic Load Control seems to be advantageous over TSC, because the graph is at the left handside with respect to the graph of TSC, also with lower peak magnitude value. But, around 26,5^{o} C-32,5^{o} C TSC case is better than the CLC case, because the number of houses having that high temperature values between this given interval is higher for CLC case with respect to TSC. So it is not possible to choose one of them as more advantageous over the other, but it can be said that TSC may be thought to be more advantageous, because the higher temperature value are more important than the lower values, as customer would face, so in the temperature interval of 26,5 $^{\circ}$C-32,5 $^{\circ}$C TSC is lower in magnitude with less number of houses than CLC. Anyway, to decide more definitely, a hybrid solution has to be applied.

5.CONCLUSION

It is observed that this new Direct Load Control method is effective in reducing peak power in noticeable rates. The studie pointed out that Thermostat-Set Control application can be better than the Cyclic Load Control case in higher temperature range. In other words, the number of houses with higher temperatures is less than that of Cyclic Load Control. This is an important result because the success of direct load control depends on the number of satisfied customers. Load managment procedures must reduce the number of unsatisfied customers to be able to use the peak load reduction methods. Customers can tolerate the increases in lower temperature region, this may not cause an uncomfortable situation, whereas the increases of temperature in higher temperature region may become intolerable for customers and they may reject the direct load control to their appliances. Thus, this thesis concludes that Thermostat-Set Control method does reduce the number of houses at higher temperature region when the direct load control action is applied to the customers.

Application of Thermostat-Set control action may result over-reduction of the load in the begining and high payback at the end of the control duration. Two solutions to this problem may be used . First solution may be, the application of Thermostat-Set Control in a whole daytime; that prevent the act like payback, leading to a severe peak as stated above; but this is not a suitable solution; because the customer's would be facing higher temperatures as a result of the load control application even at the night times; although load control is not needed at night times of a day as the temperature is not as high as the daytime, control would lower the comfort level of customers. Other solution may be groupping of the houses. Groupping would lower the number of interrupted houses in certain intervals of time and this will result with the smaller over-reduction and payback.

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APPENDICE A

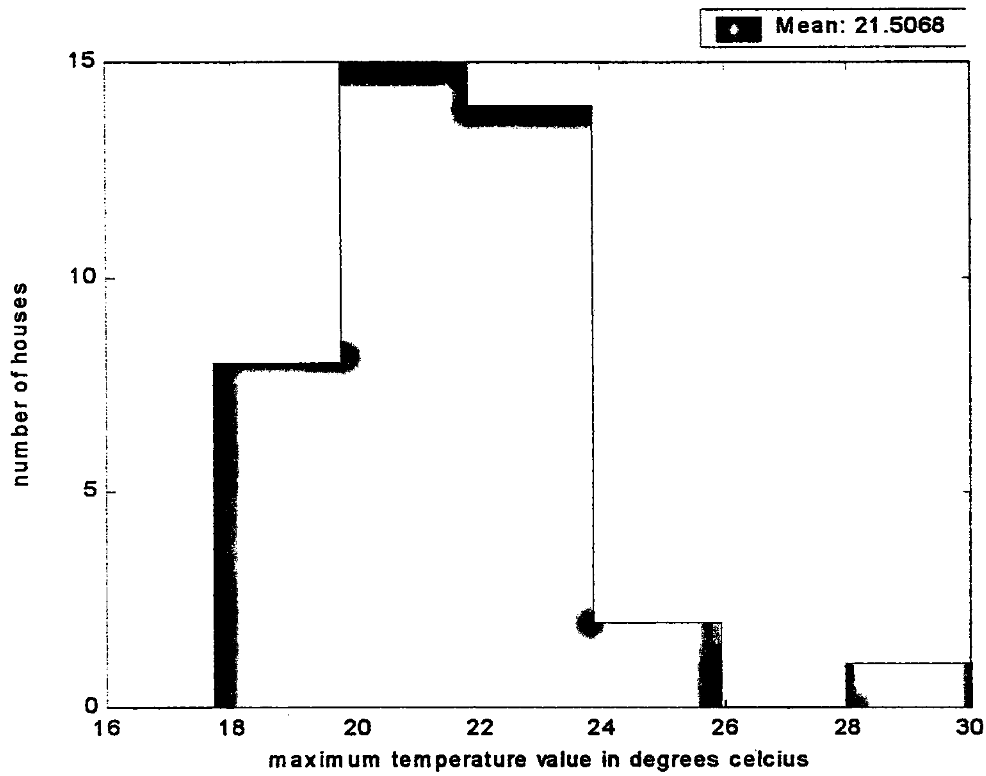

Figure A.1. Maximum temperature histogram of simulated forty houses for the case of ambient temperature 30 degrees under no control

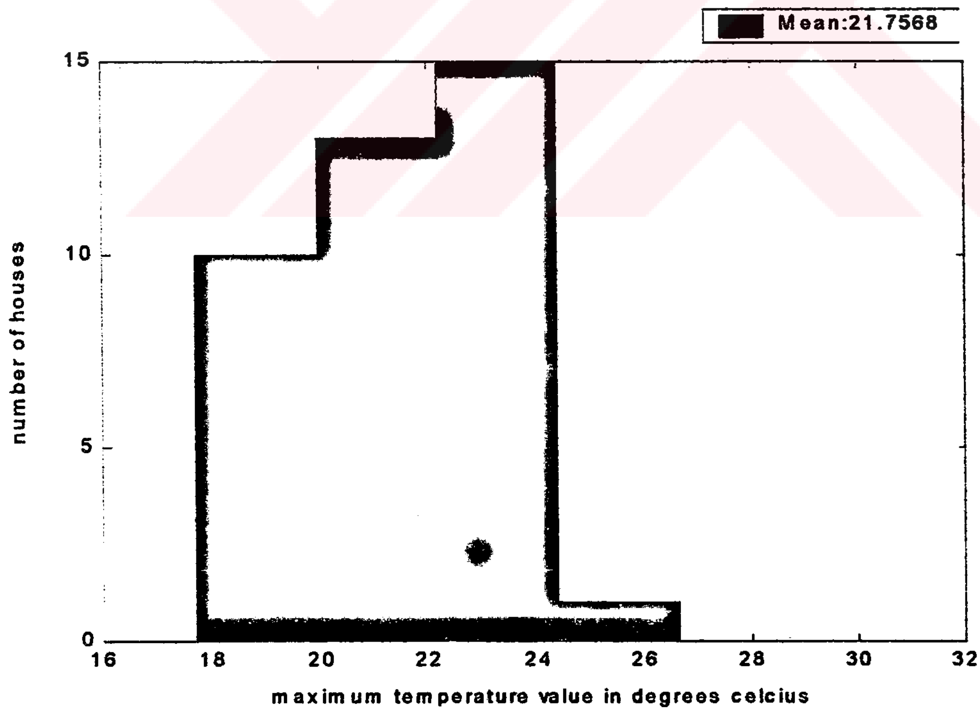

Figure A.2 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 40 degrees under no control

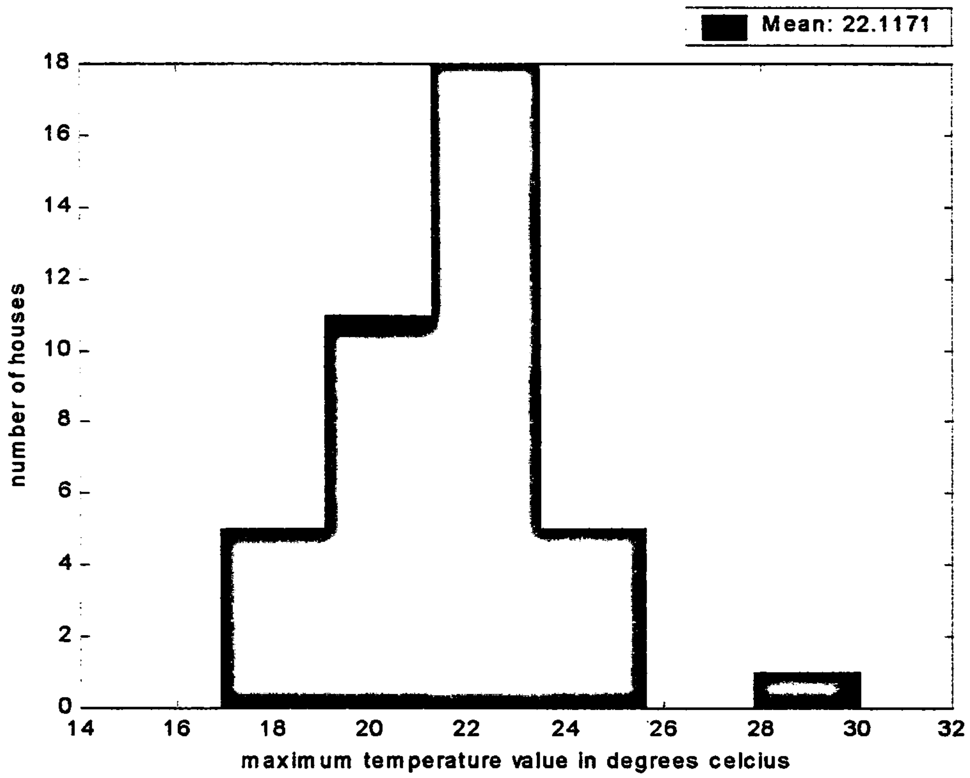

Figure A.3 Maximumtemperature histogram of simulated forty houses for the case of ambient temperature 30 degrees with %25 cyclic control

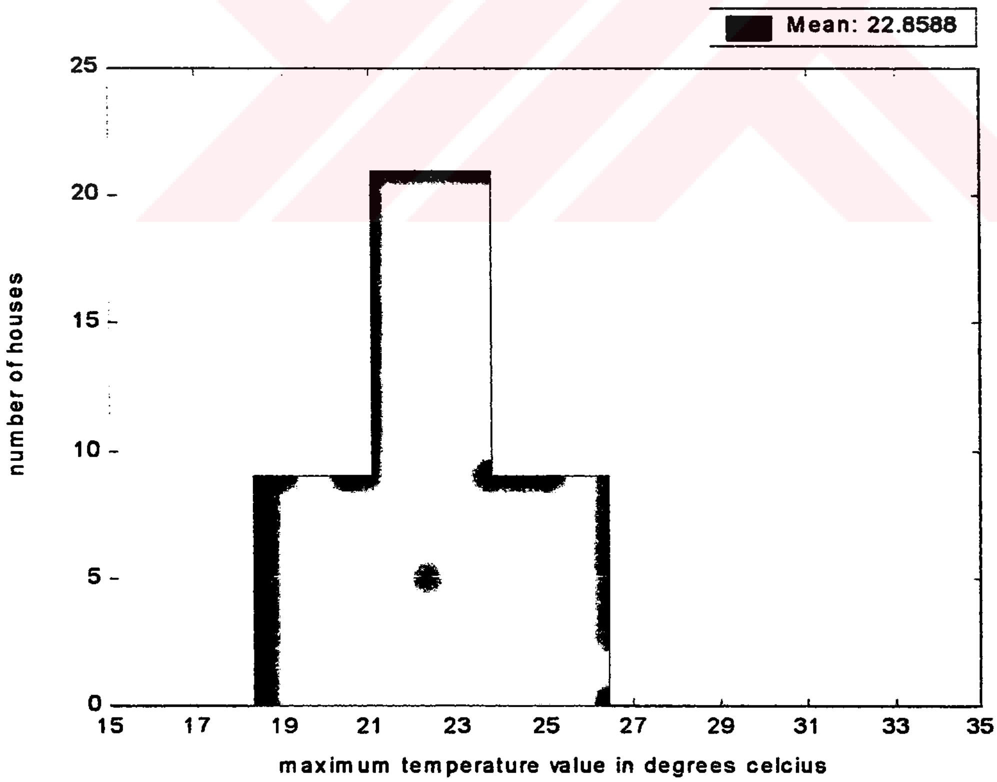

Figure A.4 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 40 degrees with %25 cyclic control

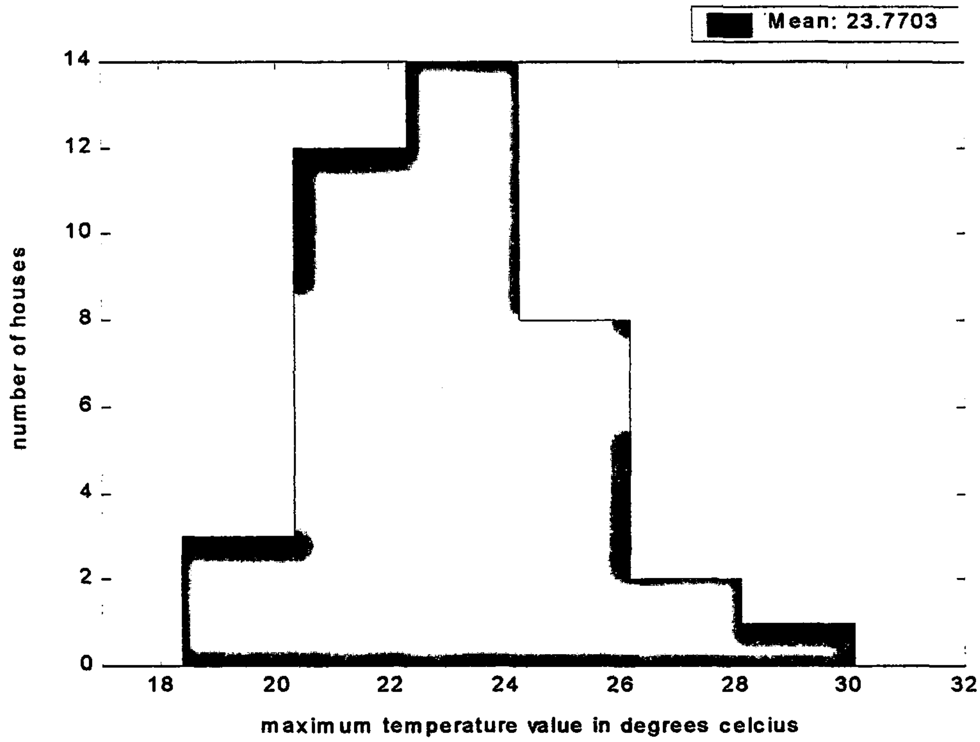

Figure A.5 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 30 degrees with 2 degrees temperature control

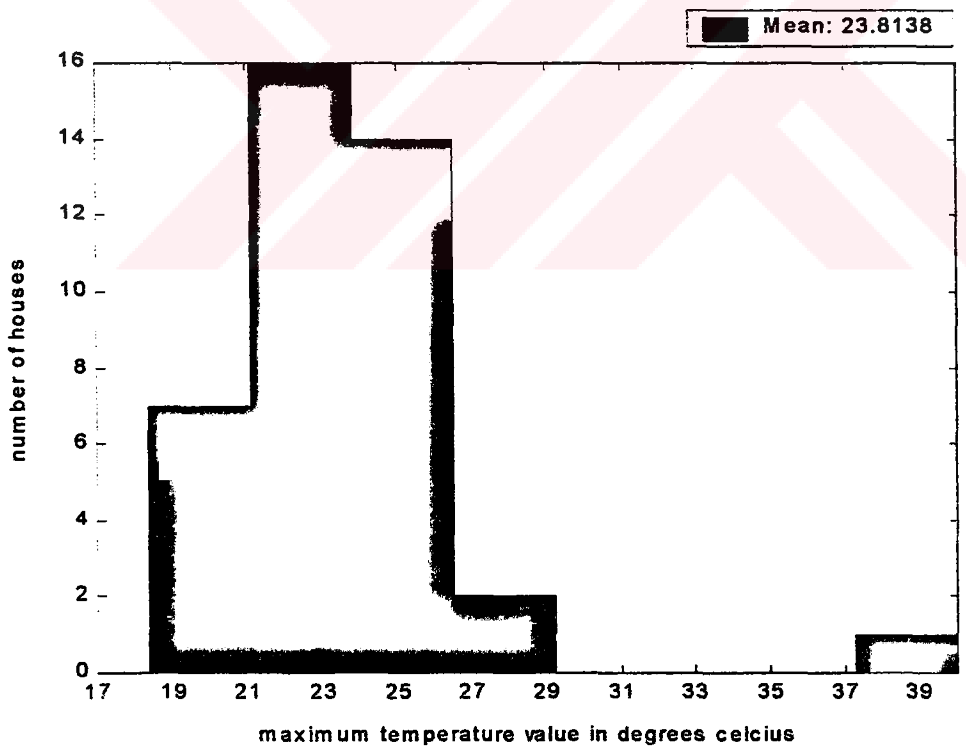

Figure A.6 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 40 degrees with 2 degrees temperature control

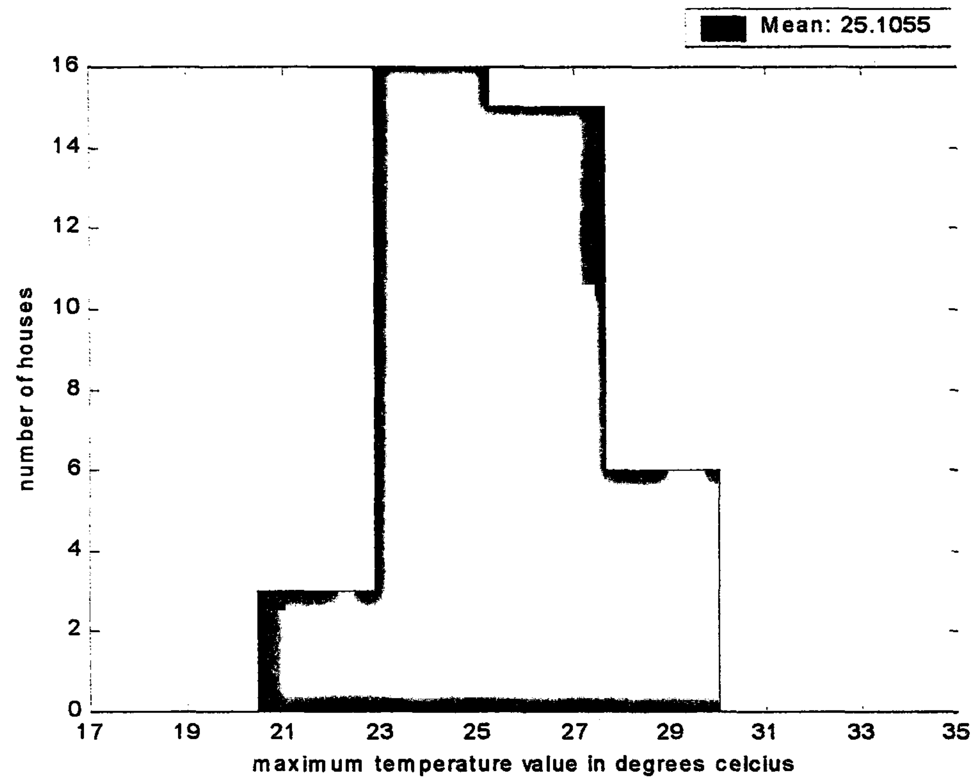

Figure A.7 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 30 degrees with 4 degrees temperature control

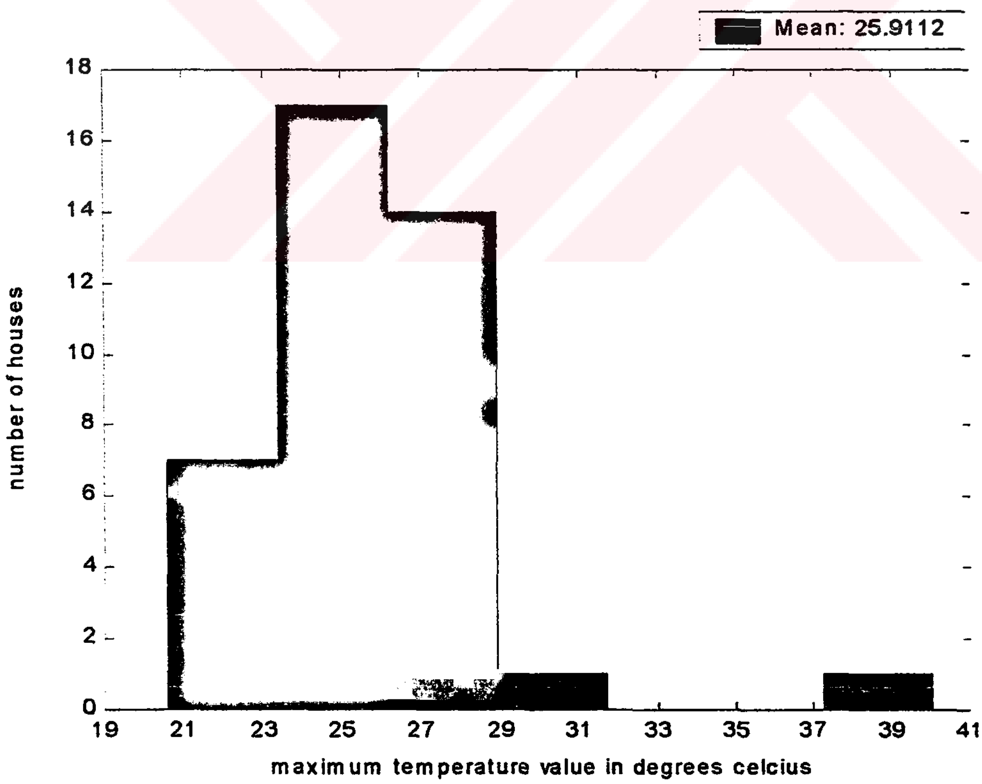

Figure A.8 Maximum temperature histogram of simulated forty houses for the case of ambient temperature 40 degrees with 4 degrees temperature control

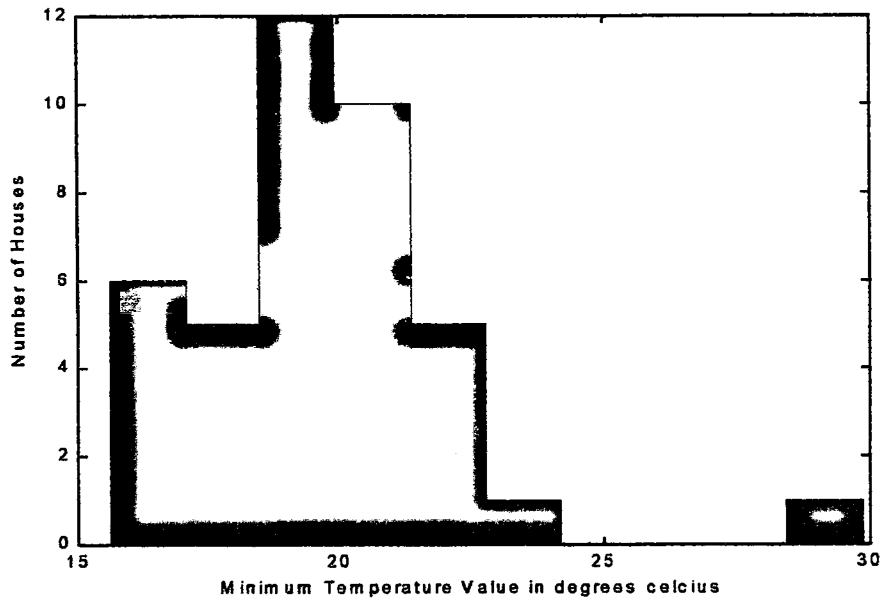

Figure A.9 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature 30 ^{o}C (without daily temp. change) under no control

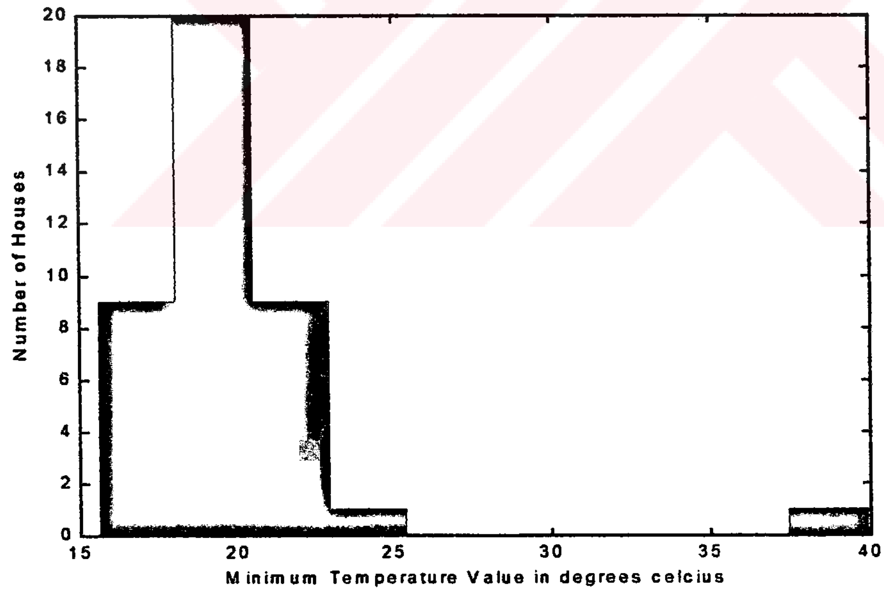

Figure A.10 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature 40^{o}C (without daily temp. change) under no control

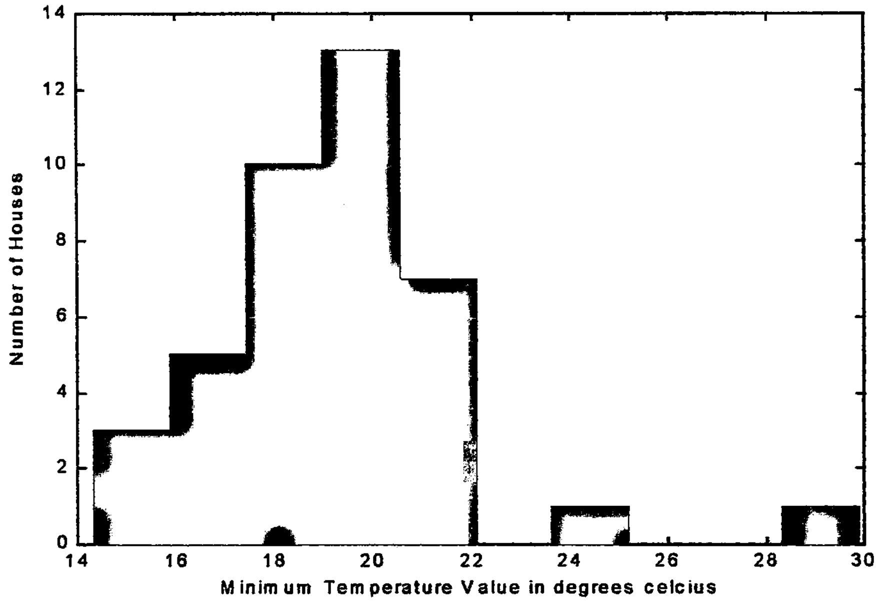

Figure A.11 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature:30^o C with %25 cyclic control

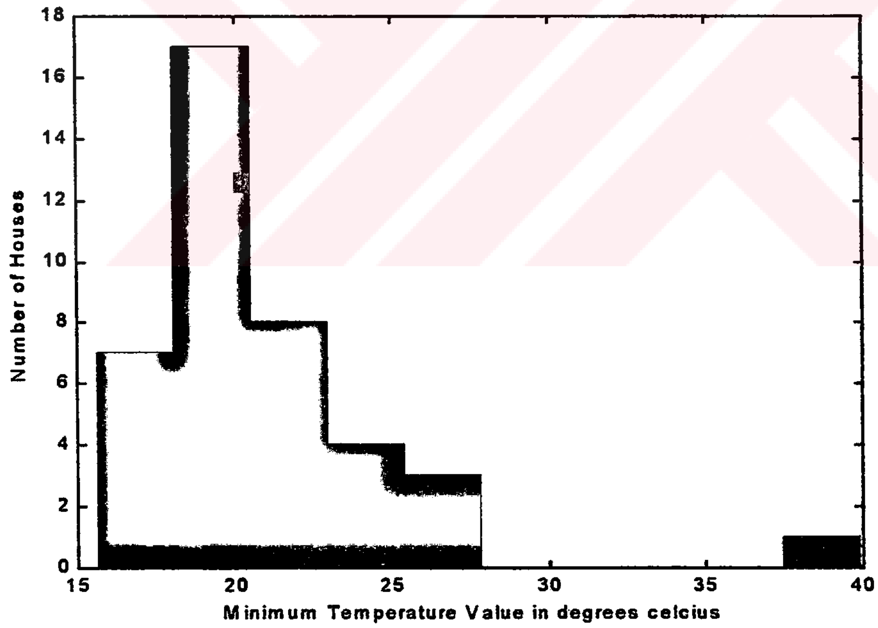

Figure A.12 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature:40^o C with %25 cyclic control

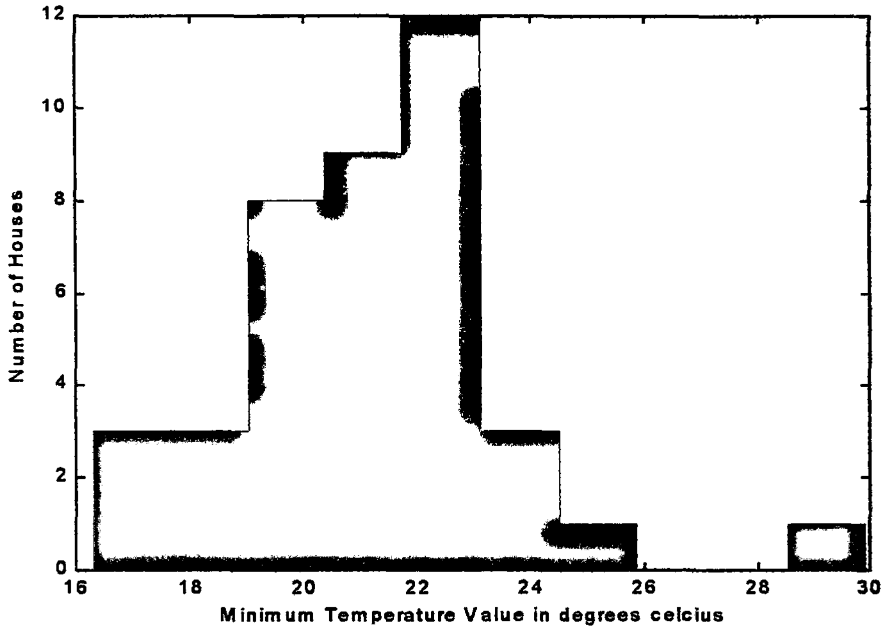

Figure A.13 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature 30 ^{o} C with 2 ^{o} C temperature control

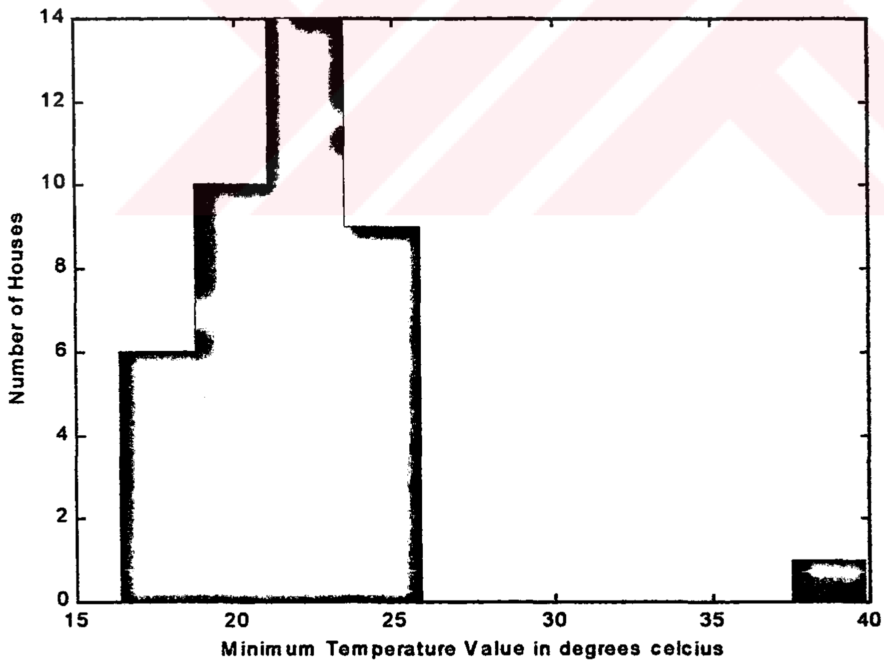

Figure A.14 Minimum temperature histogram of simulated forty houses for the case of average ambient tempearture:40 ^{o} C with 2 ^{o} C temperature control

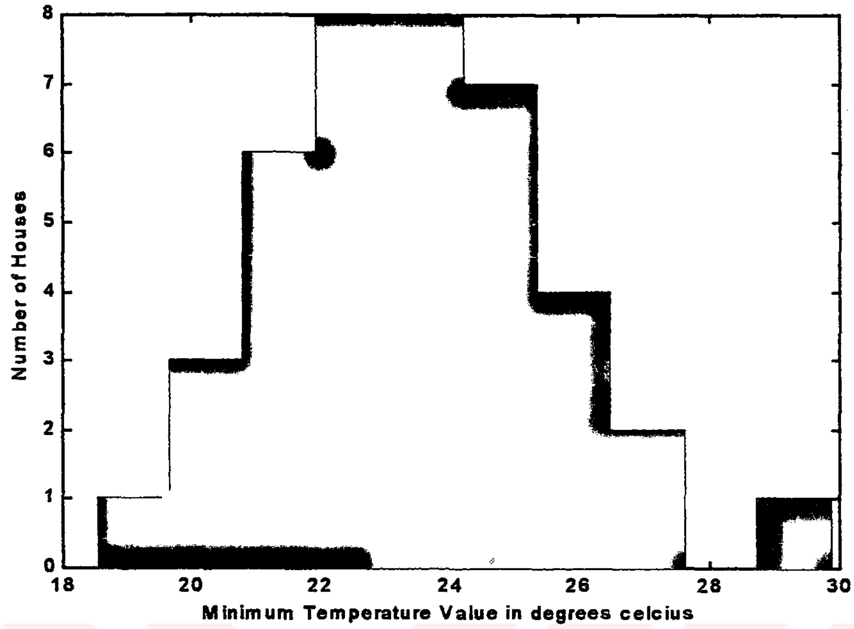

Figure A.15 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature:30^o C with 4^o C temperature control

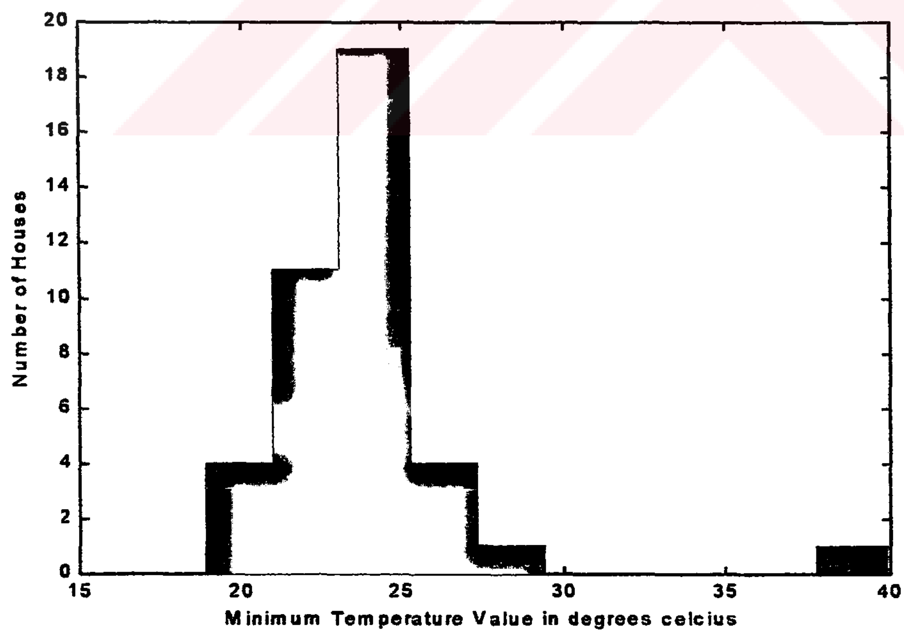

Figure A.16 Minimum temperature histogram of simulated forty houses for the case of average ambient temperature: 40^o C with 4^o C temperature control

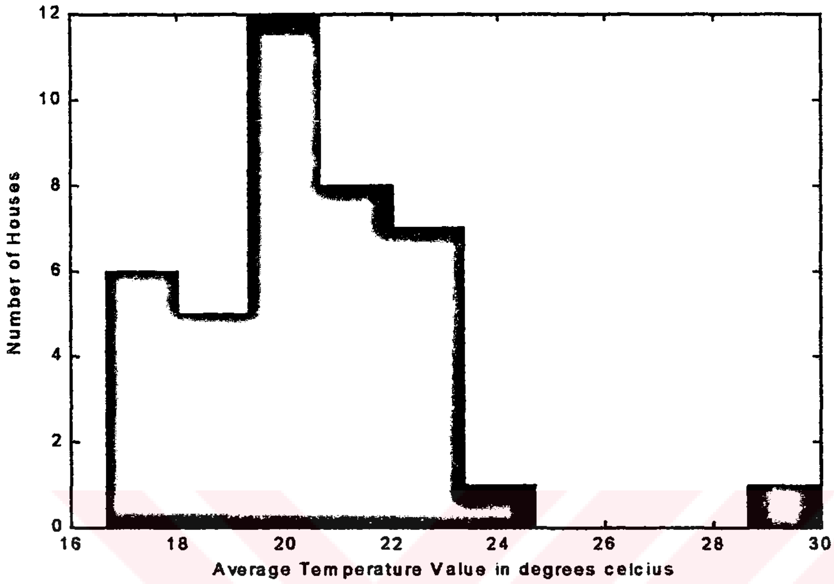

Figure A.17 Average temperature histogram of simulated forty houses for the case of average ambient temperature 30 ^{o}C without control

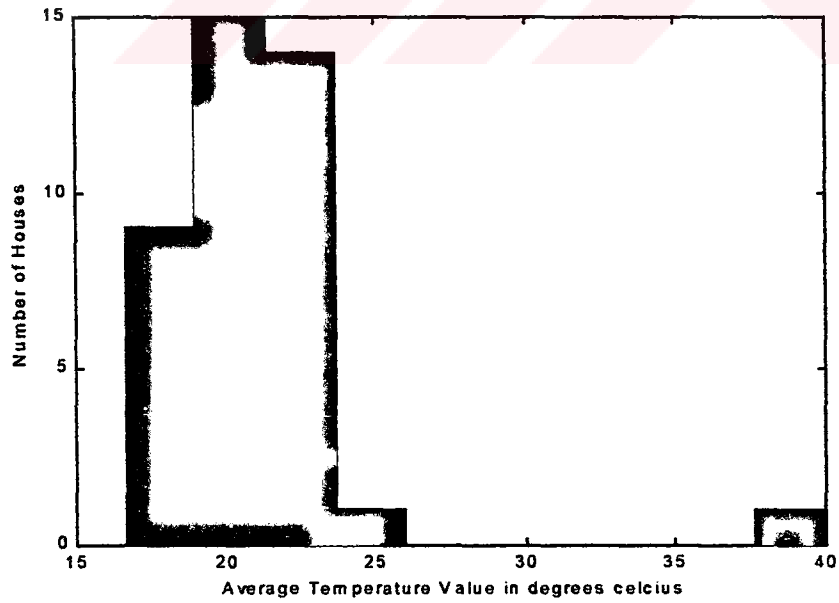

Figure A.18 Average temperature histogram of simulated forty houses for the case of average ambient temperature 40 ^{o}C without control

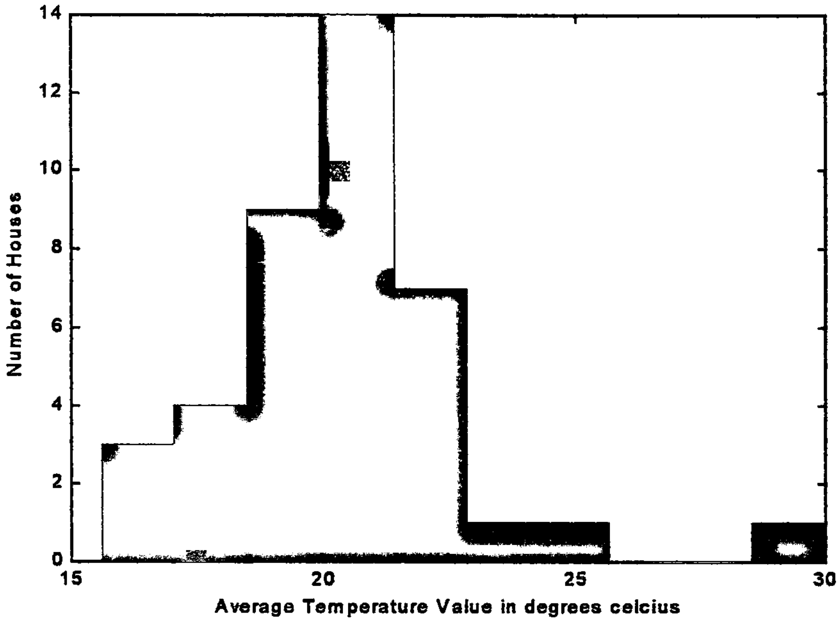

Figure A.19 Average temperature histogram of simulated forty houses for the case of average ambient temperature 30 ^{o} C with %25 cyclic control

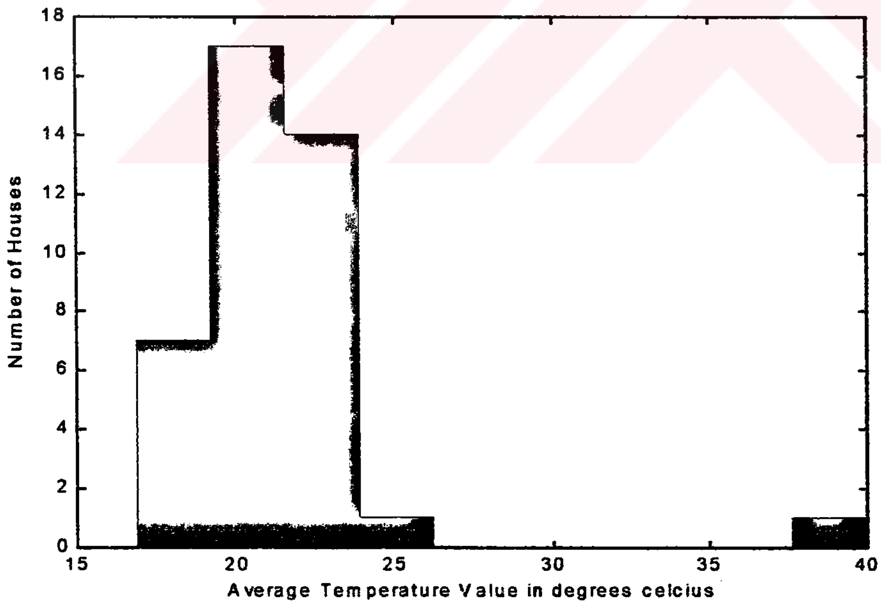

Figure A.20 Average temperature histogram of simulated forty houses for the case of average ambient temperature 40 ^{o} C with %25 cyclic control

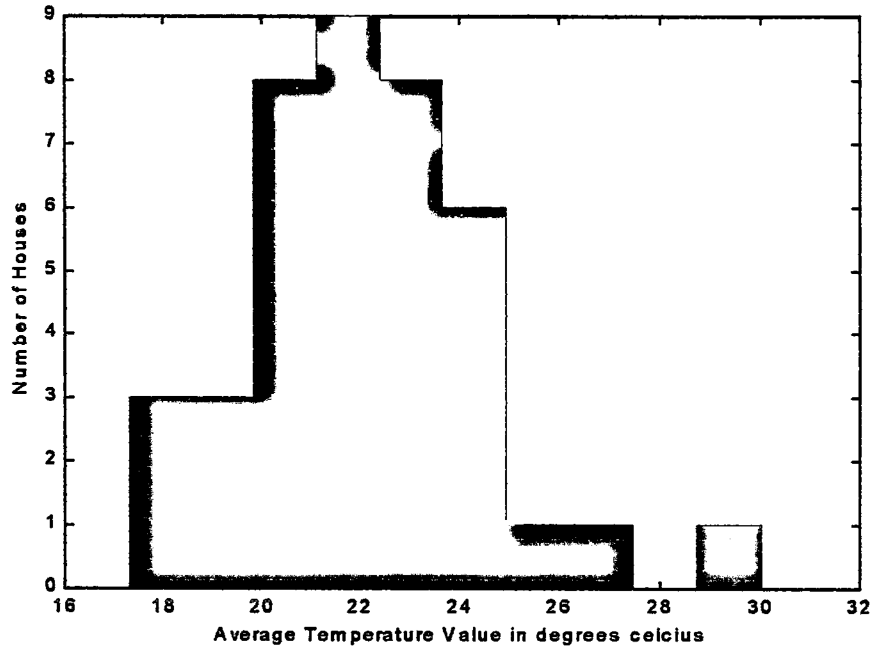

Figure A.21 Average temperature histogram of simulated forty houses for the case of average ambient temperature: 30 ^{o} C with 2 ^{o} C temperature control

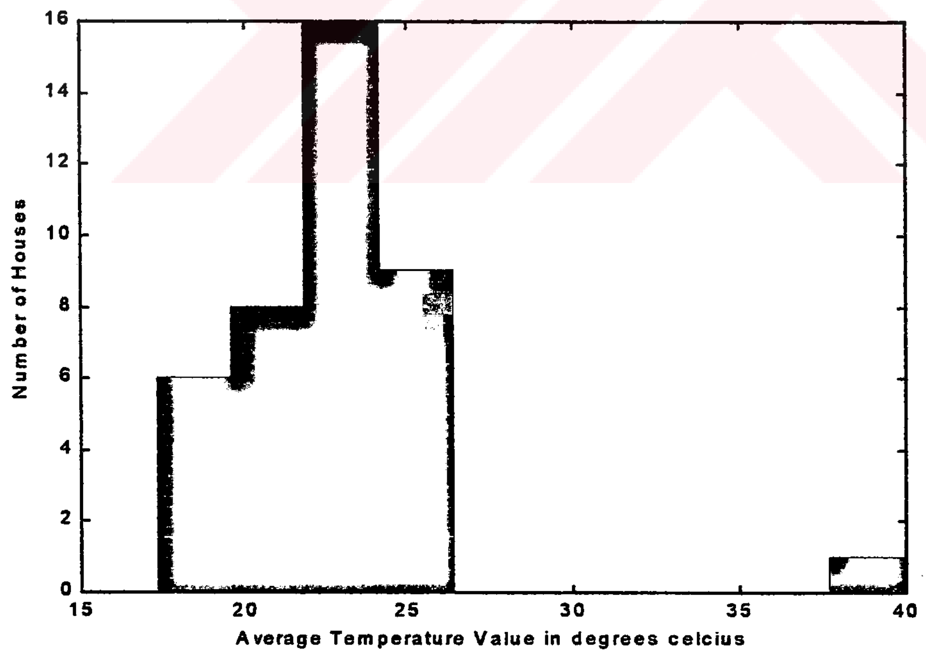

Figure A.22 Average temperature histogram of simulated forty houses for the case of average ambient temperature 40 ^{o} C with 2 ^{o} C temperature control

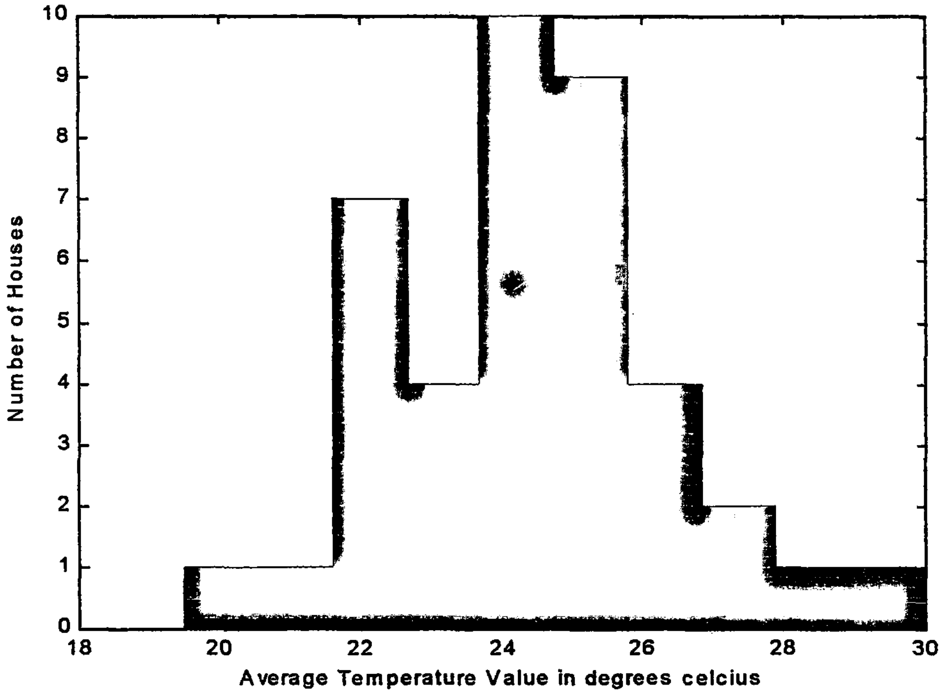

Figure A.23 Average temperature histogram of simulated forty houses for the case of average ambient temperature 30 ^{o} C with 4 ^{o} C temperature control

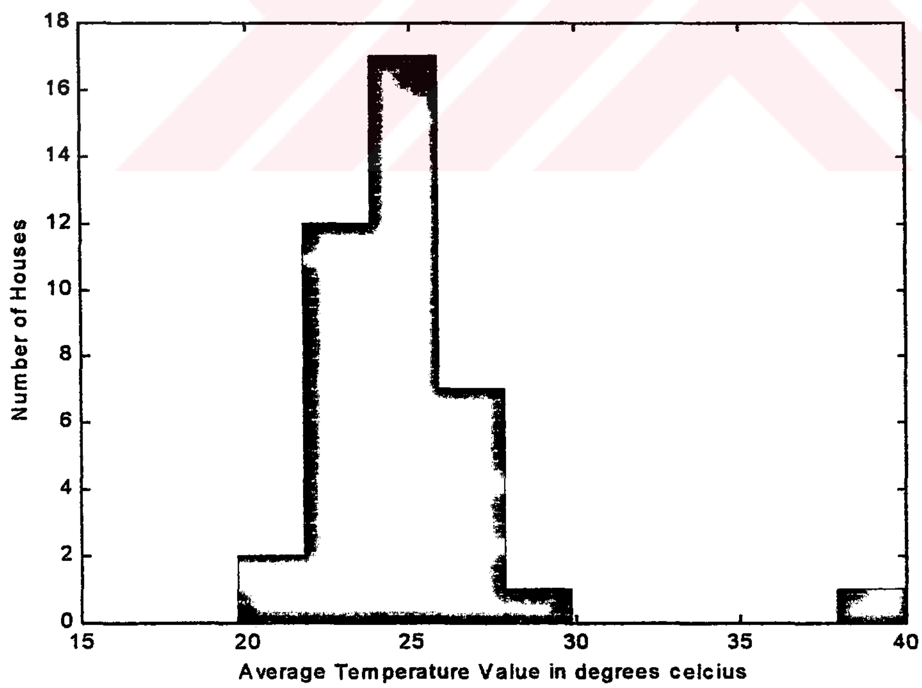

Figure A.24 Average temperature histogram of simulated forty houses for the case of average ambient temperature 40 ^{o} C with 4 ^{o} C temperature control

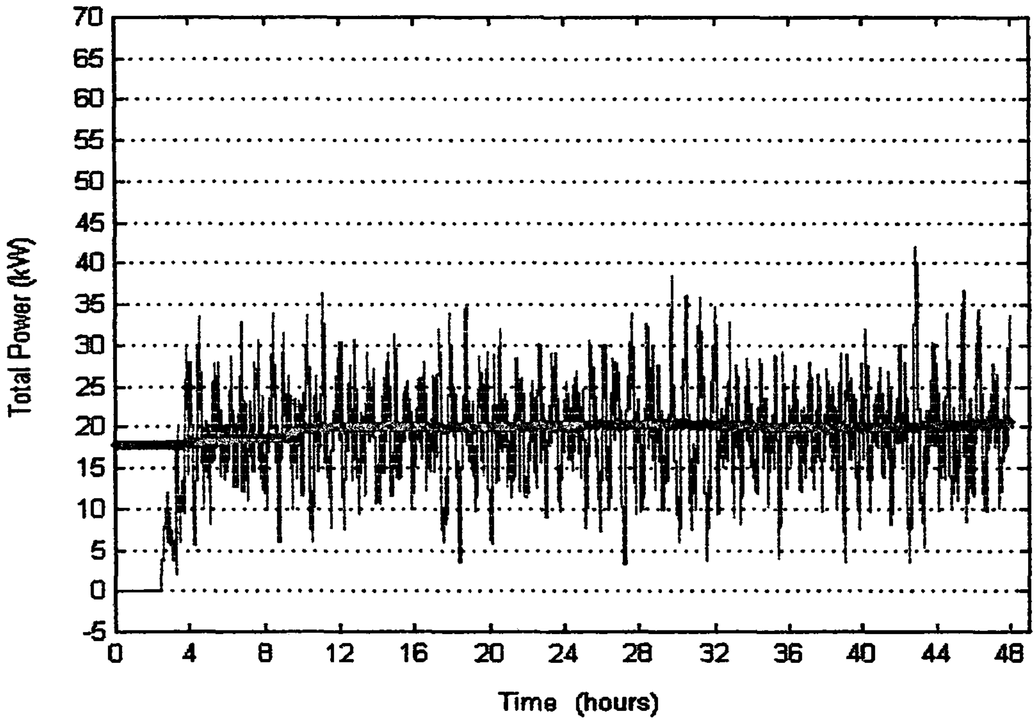

Figure A.25 Change of total power consumed by the simulated houses for the case of average ambient temperature 30 degree without control

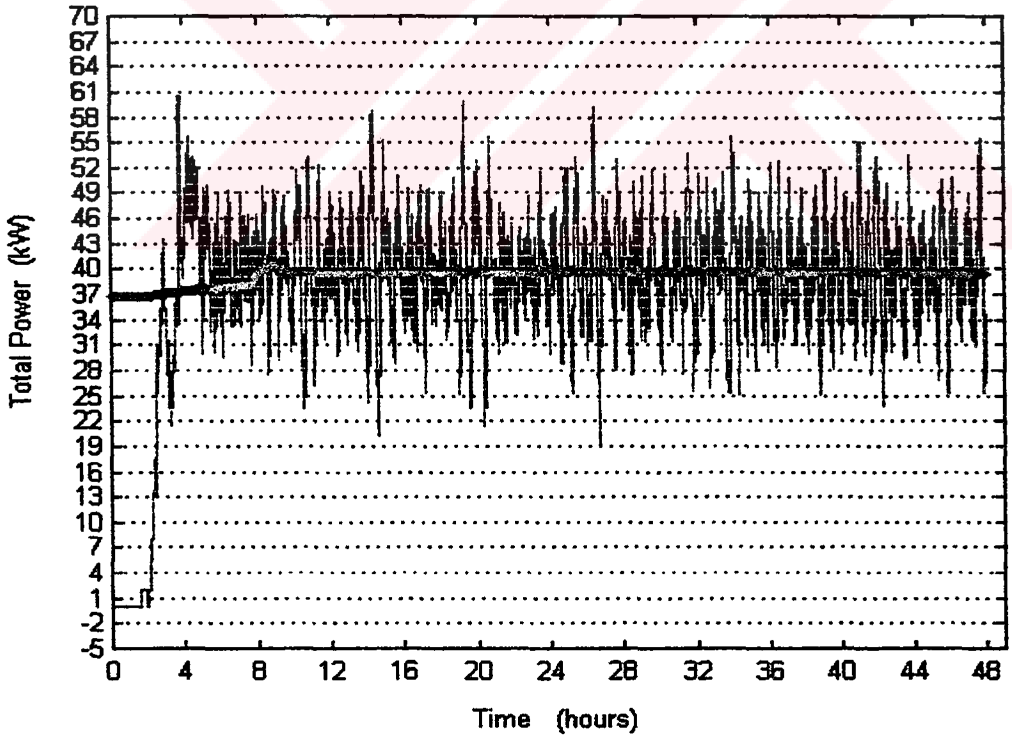

Figure A.26 Change of total power consumed by the simulated houses for the case of average ambient temperature 40 degree without control

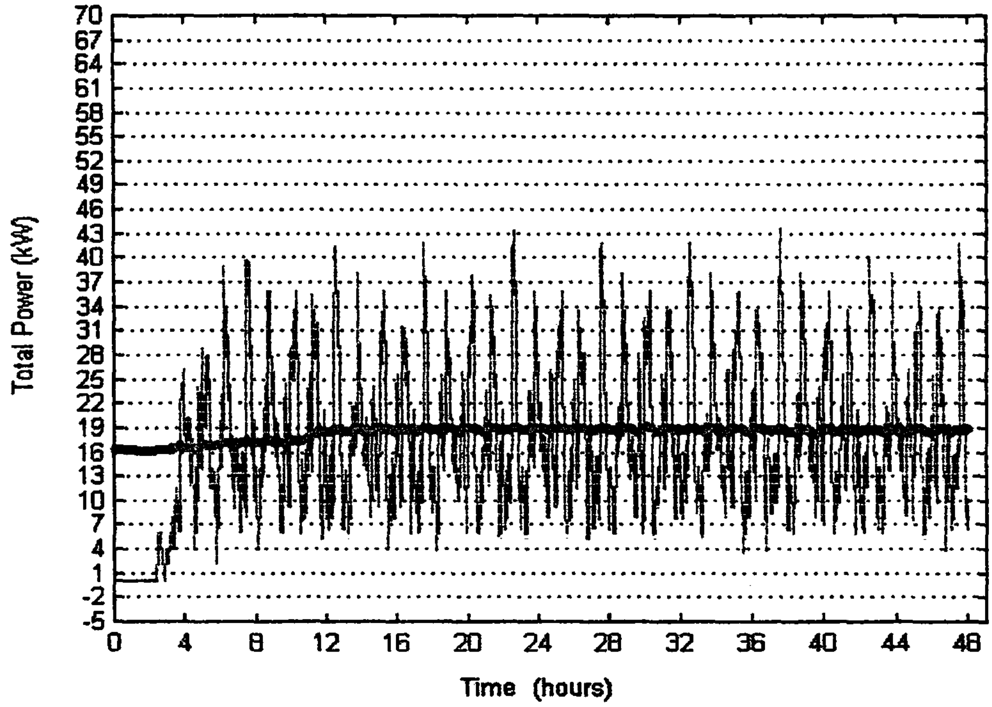

Figure A.27 Change of total load consumed by the simulated houses for the case of average ambient temperature 30 degrees with %25 cyclic load control

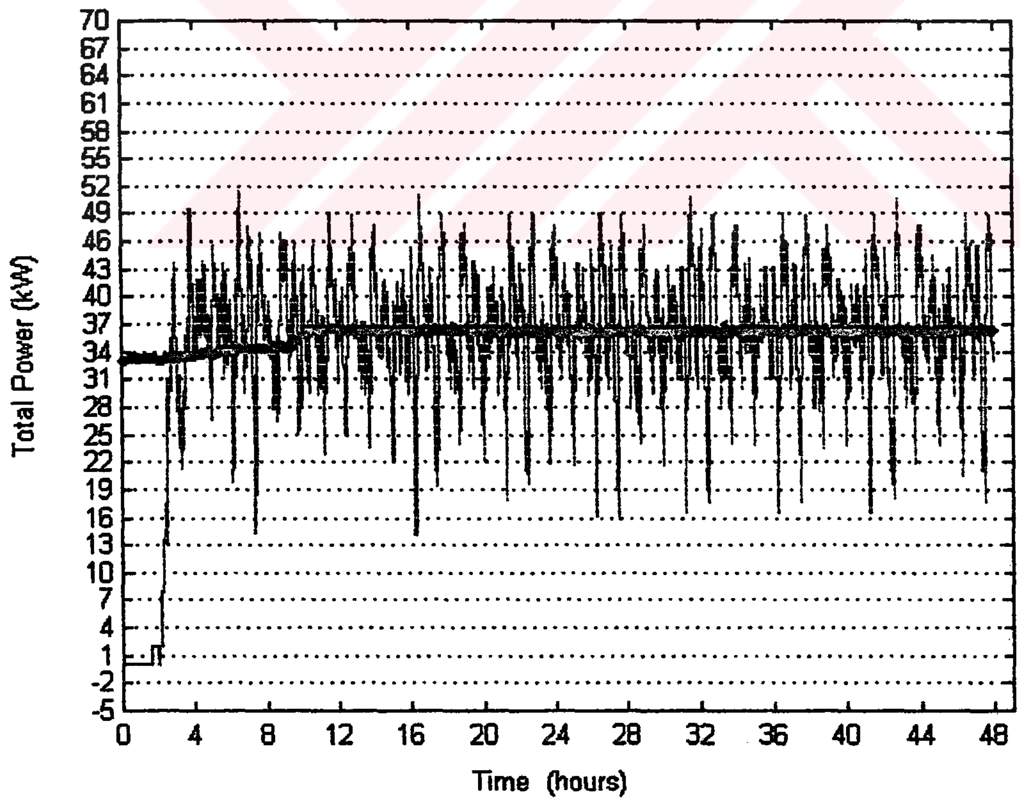

Figure A.28 Change of total power consumed by the simulated houses for the case of average ambient temperature 40 degrees with %25 cylic load Control

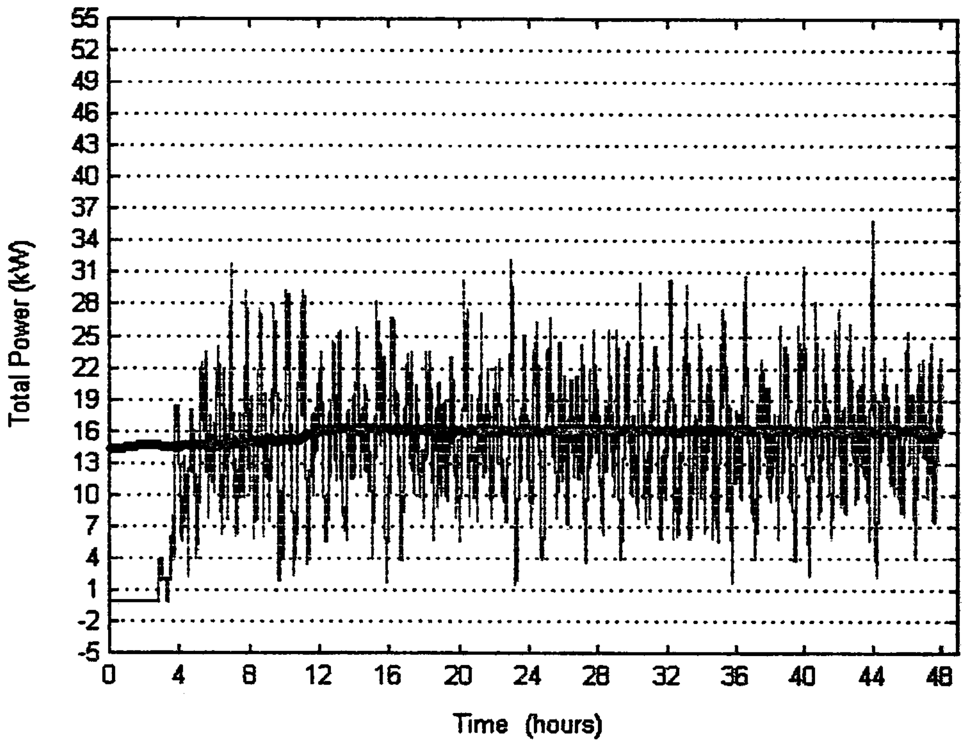

Figure A.29 Change of total power consumed by the simulated houses for the case of average ambient temperature 30 degrees with 2 degrees

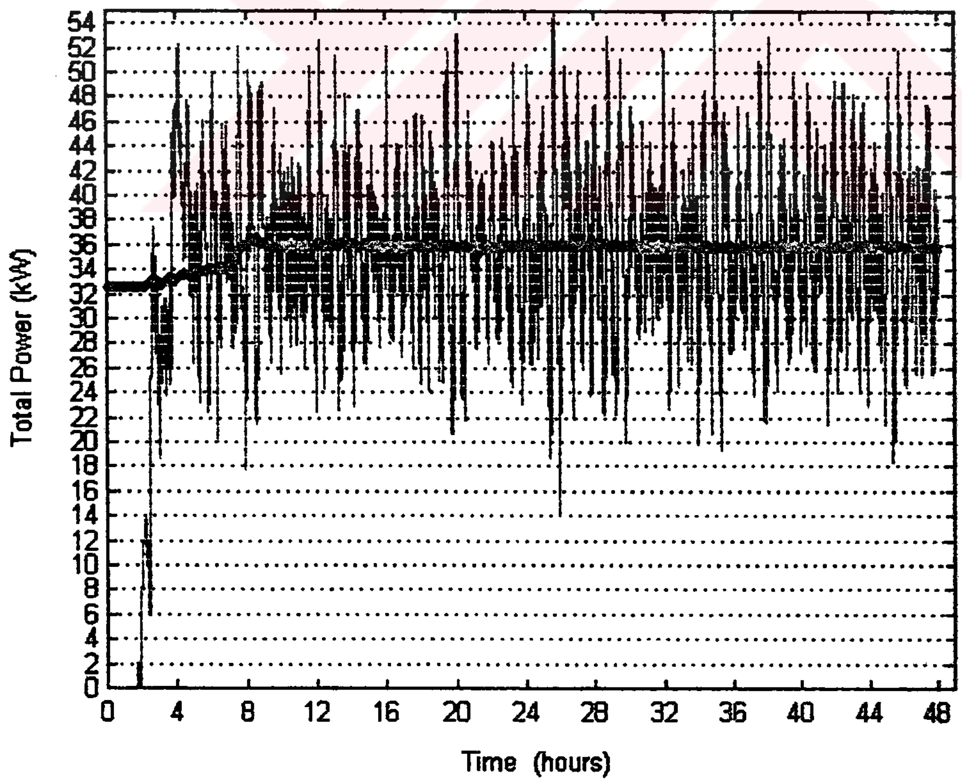

Figure A.30 Change of total power consumed by the simulated houses for the case of average ambient temperature 40 degrees with 2 degrees temperature control

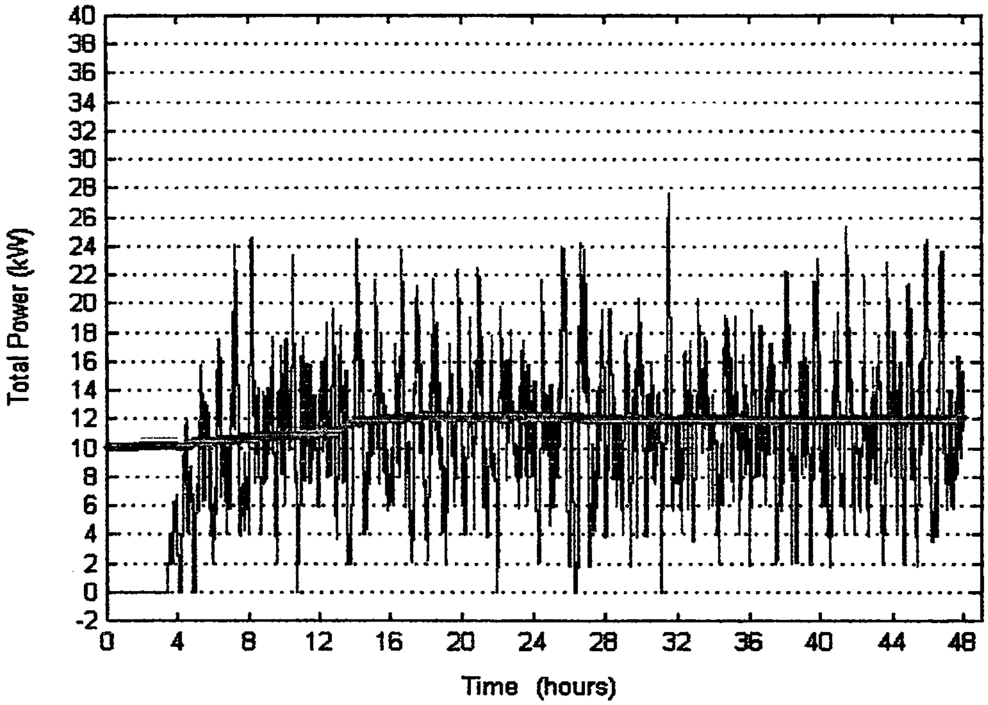

Figure A.31 Change o total power consumed by the simulted houses for the case of average ambient temperature 30 degrees with 4 degrees temperature control

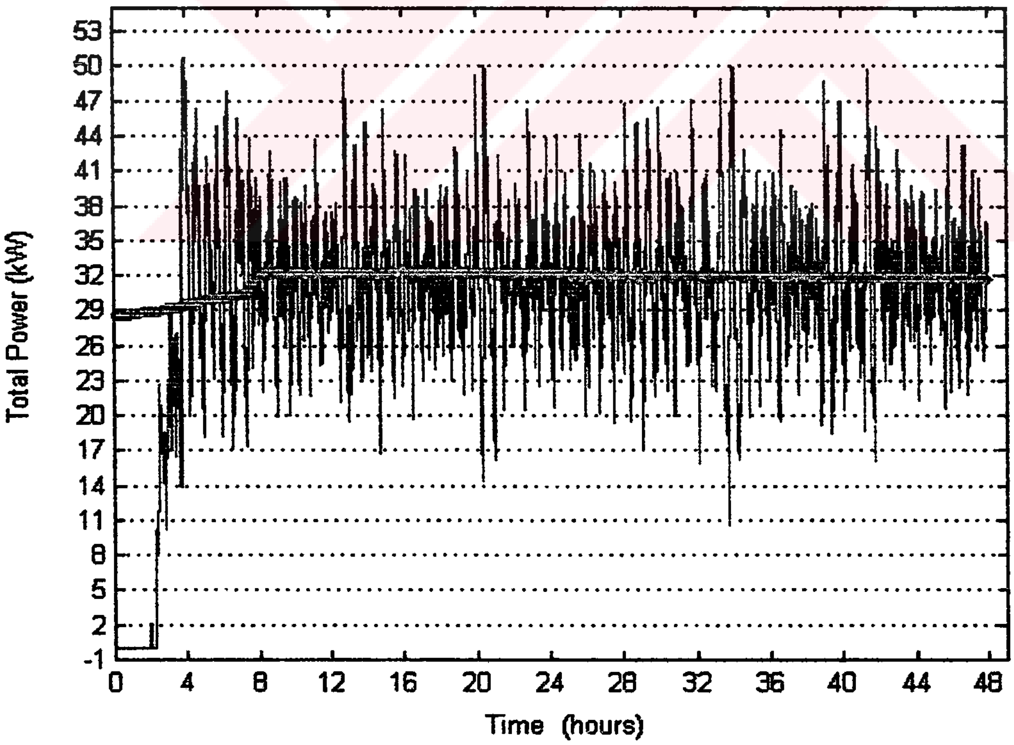

Figure A.32 Change of total power consumed by the simulated houses for the case of average ambient temperature 40 degrees with 4 degrees temperature control

APPENDICE B

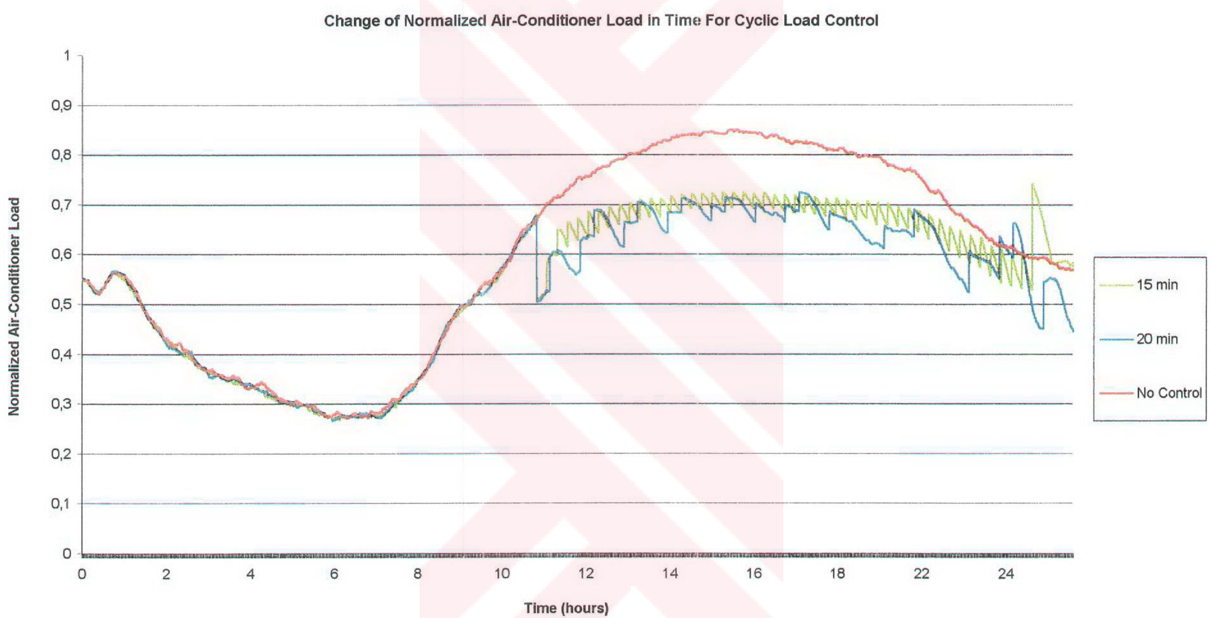

Figure B.1 Change of Normalized Air Conditioner Load in Time For Cyclic Load Control

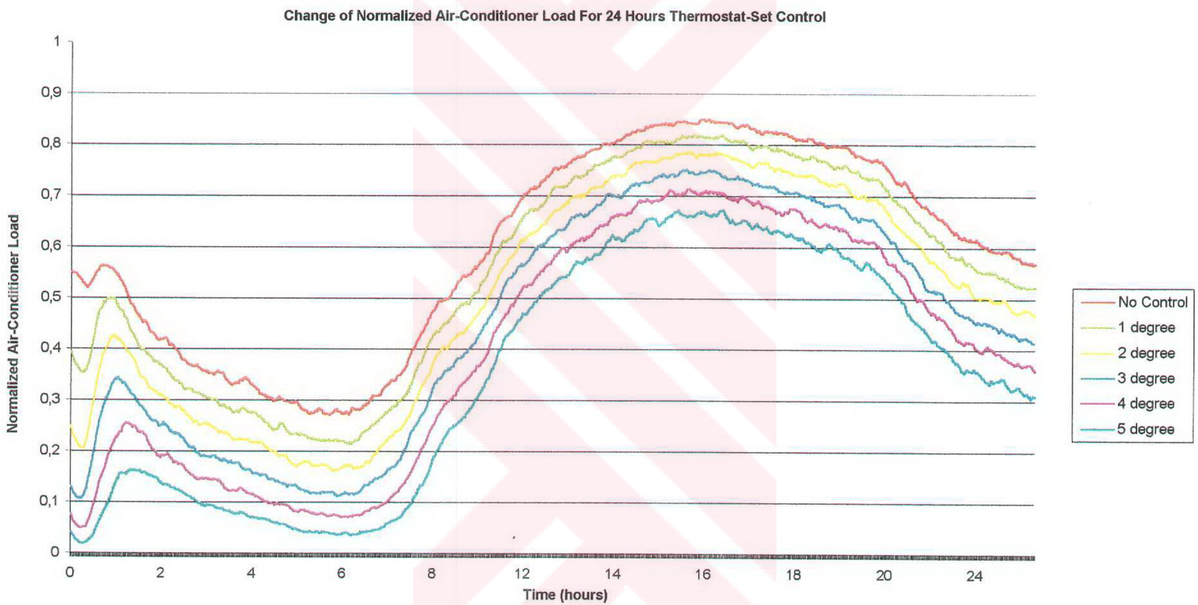

Figure B.2 Change of Normalized Air Conditioner Load in Time For 24-Hours Thermostat-Set Control

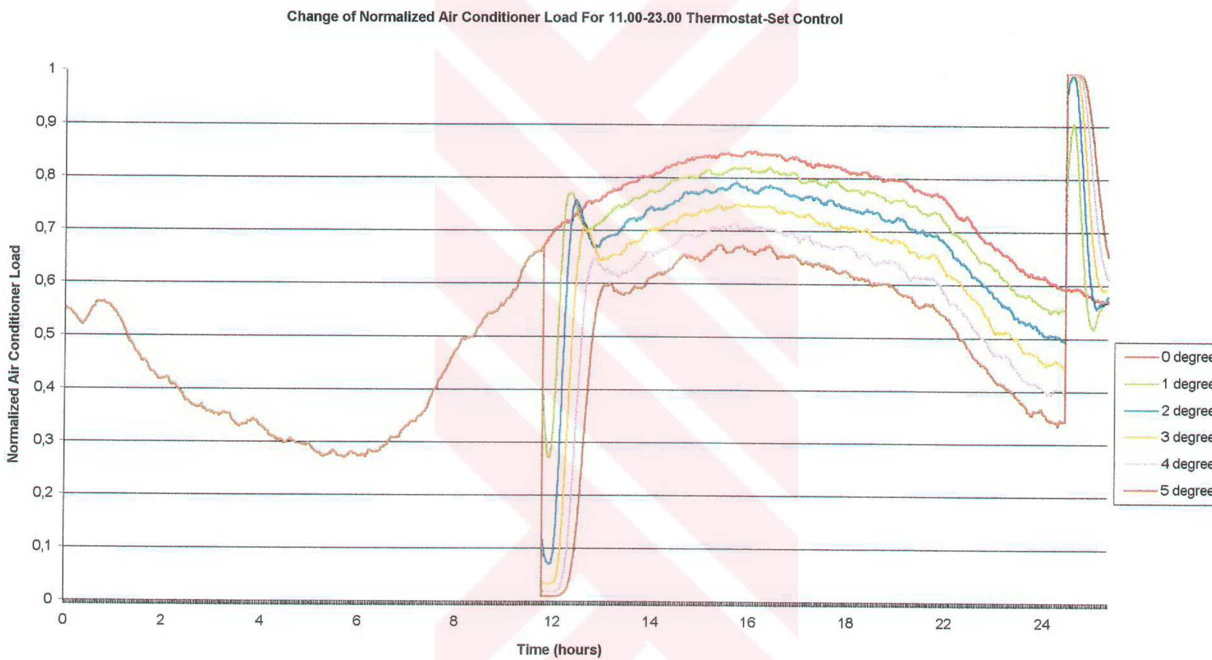

Figure B.3 Change of Normalized Air Conditioner Load For 11.00-23.00 Thermostat-Set Control

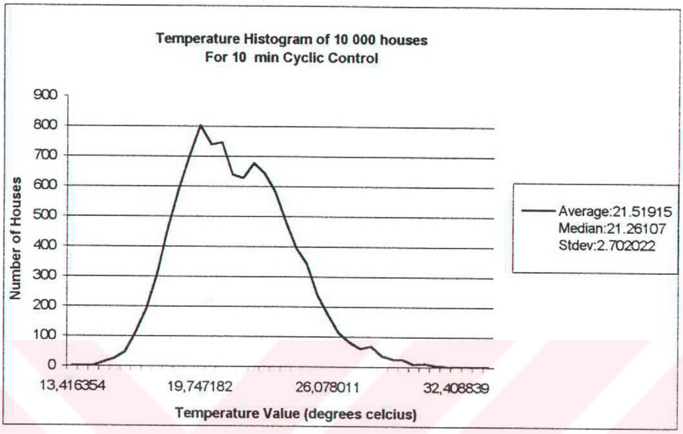

Figure B.4 Temperature Histogram of 10 000 Houses For 10 min Cyclic Control

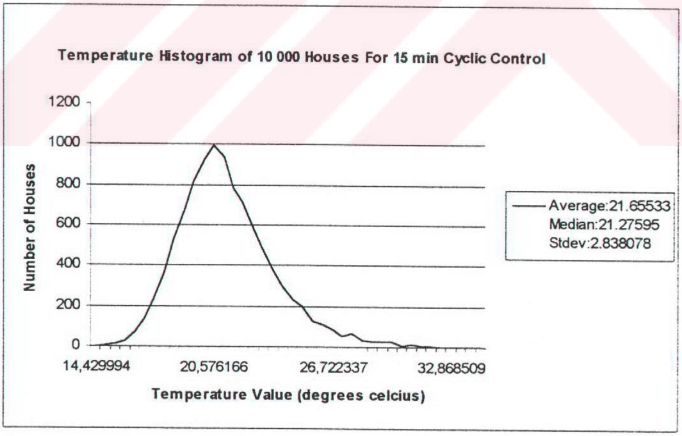

Figure B.5 Temperature Histogram of 10 000 Houses For 15 min Cyclic Control

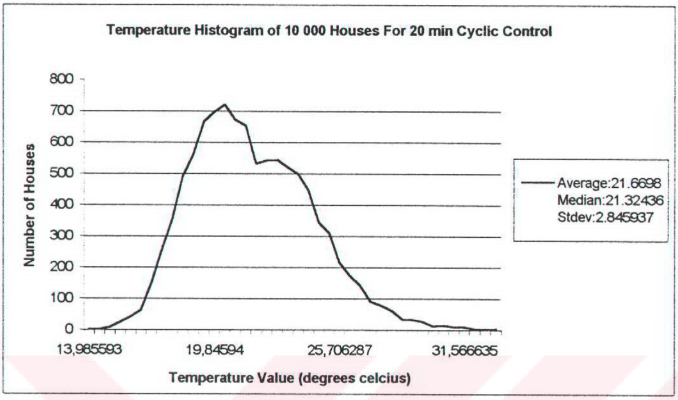

Figure B.6 Temperature Histogram of 10 000 Houses For 20 min Cyclic Control

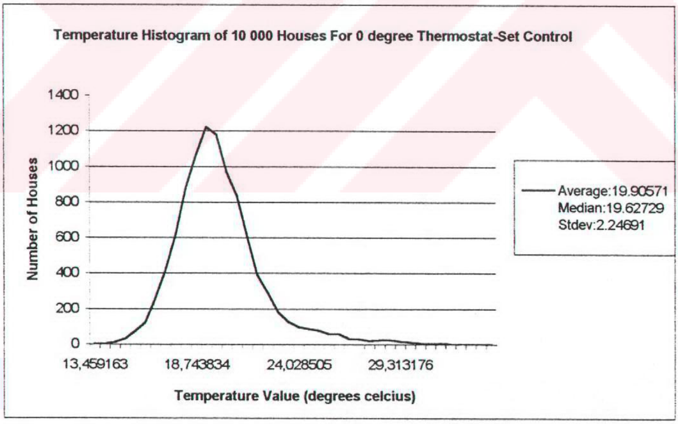

Figure B.7 Temperature Histogram of 10 000 Houses For 0 degree Thermostat-Set Control

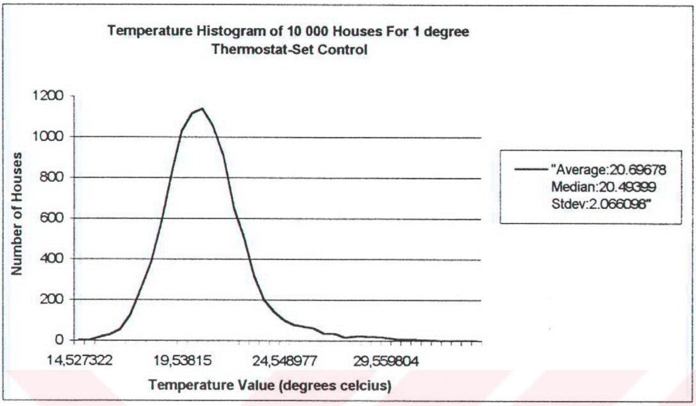

Figure B.8 Temperature Histogram of 10 000 Houses For 1 degree Thermostat-Set Control

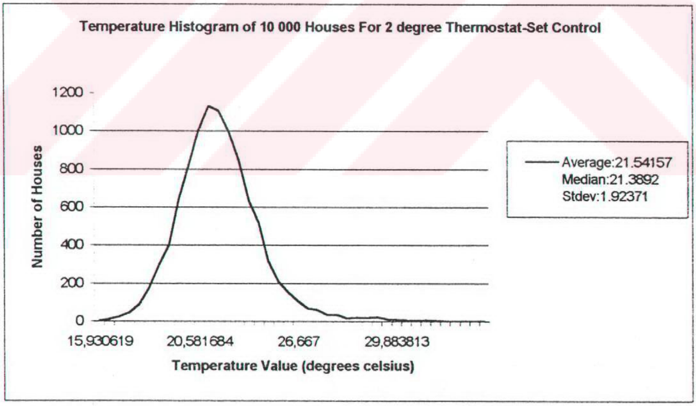

Figure B.9 Temperature Histogram of 10 000 Houses For 2 degree Thermostat-Set Control

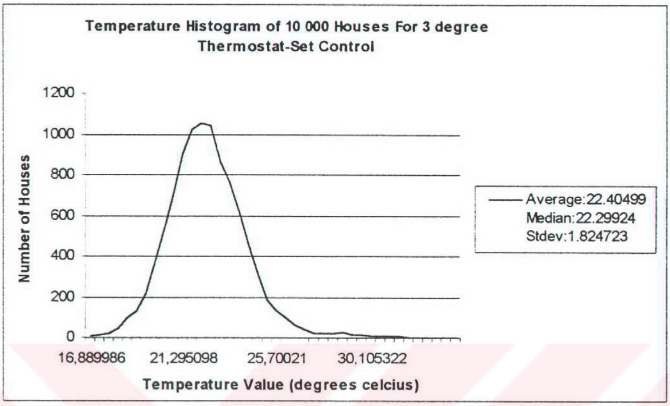

Figure B.10 Temperature Histogram of 10 000 Houses For 3 degree Thermostat-Set Control

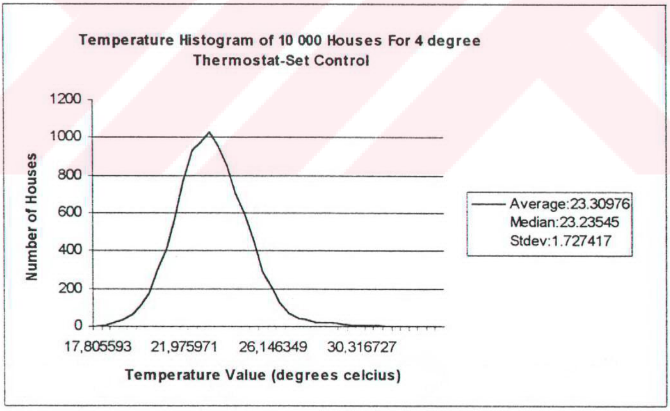

Figure B.11 Temperature Histogram of 10 000 Houses For 4 degree Thermostat-Set Control

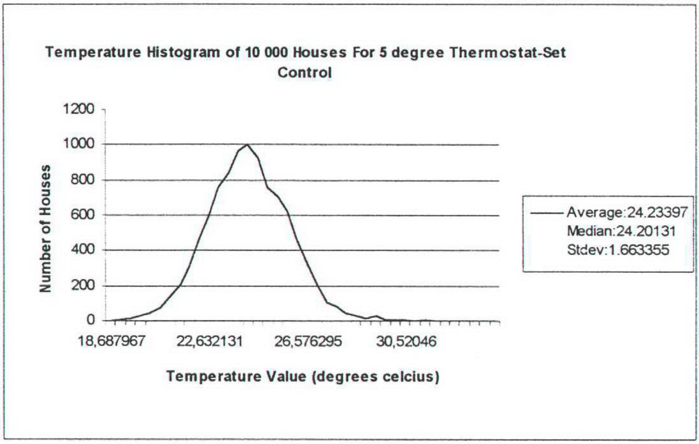

Figure B.12 Temperature Histogram of 10 000 Houses For 5 degree Thermostat-Set Control

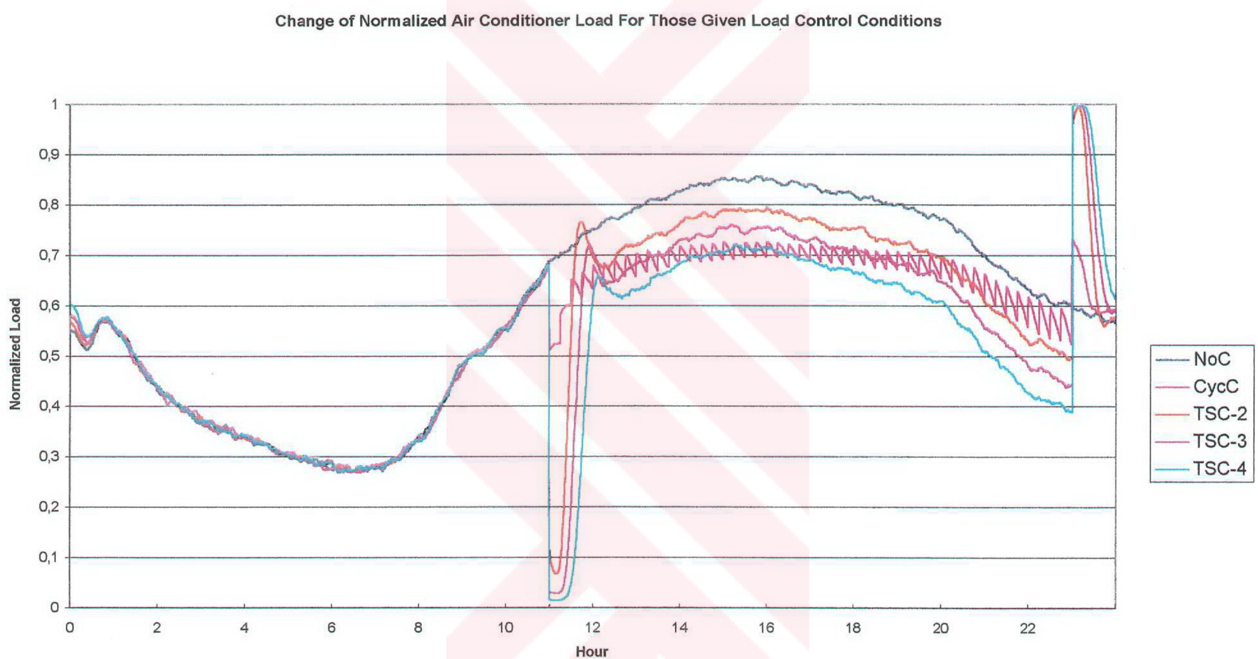

Figure B.13 Change of Normalized Air Conditioner Load For Those Given Load Control Conditions

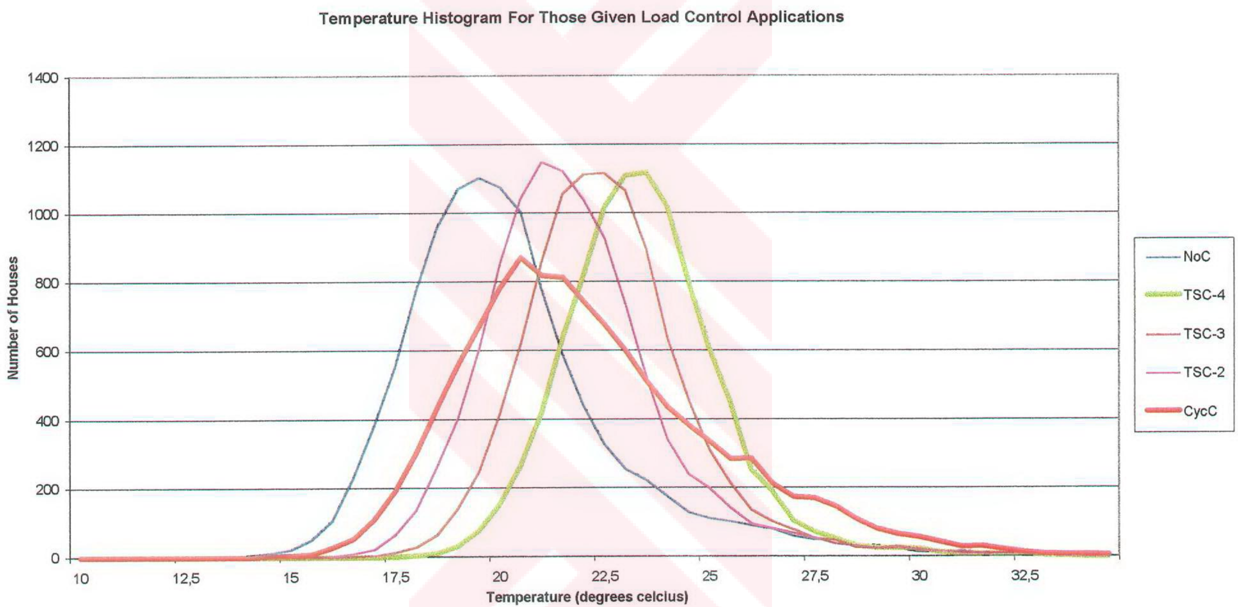

Figure B.14 Temperature Histogram of 10000 Houses For No Control, %25 Cyclic Control, Thermostat-Set Control for 2,3 and 4 degrees celcius

AUTOBIOGRAPHY

I was born in İstanbul, in 1976. I had graduated from Tercüman High School in 1991, with a good graduation degree of middleclass (ortaokul). I had graduated from Kültür College in 1994 with a good graduation degree of highschool (lise). I had continued Chemical Engineering at Yıldız Technical University for one year in 1994. I had taken ÖSYM exam again and I had been graduated from Istanbul Technical University as Electrical Engineer with 3.10/4.00 average, in the 19th place in1999. In the years 1999-2001 I had my masters education on my profession, Elecrical Engineering.

June 2001 Gökçe Dokuyucu