Optimum Power Control of Household Appliances Using IOT in Smart Buildings

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Abstract

This thesis presents a model which is developed to distribute the energy efficiently among the thermal appliances with a given capacity. This research works only on the consumer side demand management by designing admission control of the appliances. 'Progressive Filling' algorithm is adopted to develop an admission controller algorithm considering three different cases. In Matlab simulation experiment, each of the cases represents not only different energy utilization but also reduction of wastage in energy consumption. Using IOT, consumers can able to control the operations of the appliances according to their requirements and the available capacity.

Keyword- Admission control, Progressive Filling, IOT, smart building.

Declaration

We hereby declare that, this project was done under CSE497 and has not been submitted elsewhere for requirement of any degree or diploma or for any purpose except for publication.

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Letter of Acceptance

I hereby declare that this thesis is from the student's own work and best effort of mine, and all other source of information used have been acknowledged. This thesis has been submitted with my approval.

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Lastly, we owe our gratefulness to all the researchers for their works that related to our thesis and help us to learn and implement our thesis work.

Abbreviation and Acronyms

IOT: Internet of Things

AC: Air Conditioner

PI : Proportional-integral

HVAC : Heat Ventilation Air Conditioning

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Chapter 1

Introduction

1.1 Power Consumption

1.1.1 Worldwide Power Consumption

According to the International Energy Outlook 2016 (IEO2016) Reference case, the energy consumption in buildings increases on an average of 1.5%/year worldwide from 2012 to 2040[1]. As the urbanization has increased, around 80% of people in the world have electricity access. The household power consumption in the U.S is about 11,700 kWh each year where in France it is 6,400 kWh. In the UK and China, it is 4,600 kWh and 1,300 kWh. In 2010 the global average was roughly 3,500 kWh [2]. Countries of the population with less than 5 percent living below the poverty level have four times higher energy consumption. North America consumes 26 percent of the world’s energy where Europe consumes 33 percent [3]. According to the Lawrence Livermore National Laboratory (LLNL) [4], the efficiency of energy usage is 39 percent, that means more than half of energy is wasted because of inefficiencies.

1.1.2 Power Consumption in Bangladesh

Earlier, from 1995 to 2010, agriculture and industrial sectors consumed about 45 percent of total electricity [5]. As the population is increasing, the demand for electricity power is also increasing. In Fiscal Year 2016, around 66 % of the total population has direct connection to the grid where the total Generation Capacity (June 2016) was 12,365 MW and Maximum Demand was 9,600 MW. Power consumption per capita was around 251 kWh [6]. Residential sector consumes around 47% of the total energy [7]. On 1st February 2017, Bangladesh Power Development Board updated that Installed Generation capacity including Captive Power has increased to 15,379 MW [8]. But this energy power in not utilized in a proper way for which a huge amount of energy is wasted in residential and commercial sectors. This wastage can be minimized by using IOT which utilizes the building consumption in an efficient way.

1.2 About IOT

Internet of Things (IOT) is an internetworking system which is used to send data or information through any input device to a server and a specific decision making process or algorithm is applied to control the household appliances based on that data or information. '*Smart Building*' or '*Smart Home*' is a real world application of IOT. In a smart building or smart home, all the physical objects or devices are interconnected through a network and they use sensors, actuators, microchips etc to collect user data or environment data and automatically control the operation of the building. For example, user can give a command to the system to switch on the air conditioning before entering home or update the stock of refrigerated items. In regular basis, switch off lights after leaving home, unlock the doors when no one at home etc, ventilations are some of smart operations of the building. It helps to improve the resource performance, utilize the energy consumption and reduce the environmental impact of the buildings. In this research we work on the optimization of the power consumption of the thermal appliances of a building ensuring the comfort level of the temperature.

1.3 Motivation

Our work is motivated by the fact that appliances operations can be controlled in a practical environment. So it is important to build a system that will encapsulate the appliances functionality, ensure cooperation between them, provide easy maintenance and allow upgrading the system with the fast moving world.

1.4 Objectives of the Research

In this research, our main purpose is to distribute the total energy among the appliances with the limited capacity. Our goal is to develop an algorithm through which we can distribute the power among the appliances in an efficient way.

Another purpose is to reduce the energy consumption significantly. We can also control our appliances over IOT and distribute the power among the appliances. Here the appliances can be controlled remotely to reduce the total energy consumption.

1.5 Scope

A layered architecture is proposed in [9] consisting three layers: Admission Controller(AC), Load Balancer(LB), Demand Response Manager(DRM). In our research, we consider only the lower layer or bottom layer (Admission Controller) of the architecture. Upper layers are beyond of our research.

We only consider the consumer side demand management to optimize the energy consumption of residential and commercial buildings. The generation or the national grid is beyond of our research.

1.6 Outline of the Research

Chapter 1 provides an overview of IOT in smart building. It also discussed about the worldwide power consumption and consumption in Bangladesh. Our motivation and objectives of our research are also discussed here.

Chapter 2 presents the related works of our research.

Chapter 3 presents thermal models and the methodologies to distribute the energy with a limited capacity.

Chapter 4 reports the experimental setup and experimental results of our simulation models. It also shows effective distribution of power by analyzing and comparing the models.

Chapter 5 overviews the summery and future research works.

Chapter 2

Literature Review

2.1 Introduction

Reducing power consumption and improving the effective and efficient use of energy in building motivate the development of smart grid. One of the key concepts of smart grid is Demand Side Management (DSM). It is the "planning, implementation and monitoring of those electric utility activities designed to influence customer uses of electricity in ways that will produce desired changes in the utility's load shape"[11]. It helps the customer to reduce their electricity demand and allows shifting their load consumption pattern during peak period so that the grid is not overloaded by consumer demands. Through this approach a consumer can:

- Consume the energy when it is cheaper and thus reduce the energy cost and save money.
- Reduce the energy shortages.
- Protect the environment by their green behavior.

2.2 DSM System Architecture

For managing the load efficiently, three categories loads are introduced based on the basic characteristics of the appliances. Three loads are:

- **Baseline load**

  The request of these loads can come at anytime so that some power can be reserved to accept these requests. Baseline load includes lighting, computer, fan, cooking stove, TV etc. The operation of these loads is not handled by admission controller. So they consume power and perform their operations according to the requests coming from the consumers.

Figure 2.2.1: Baseline Load.

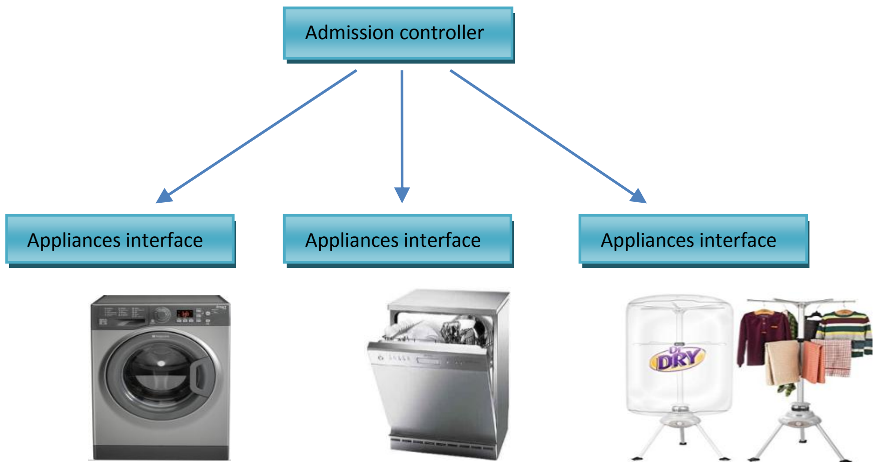


Figure 2.2.2: Burst Load.

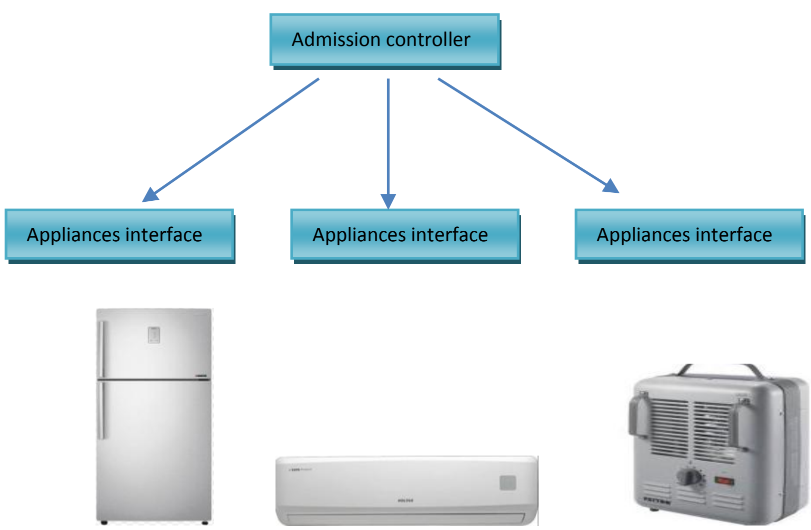


Figure 2.2.3: Regular Load.

❖ Burst load

These loads have some fixed time period to start and finish their operations. Burst load includes cloth dryer, washing machine, dishwasher etc. Managing the burst load efficiently is one of the critical issues which have a significant impact on the efficient power consumption and energy price on demand side.

❖ Regular load

These loads can always be in the running state for a long time period. Regular load includes air conditioning, heating, refrigerators, HVAC (Heat Ventilation Air Conditioning) etc. Their operation is controlled by admission control based on their priority.

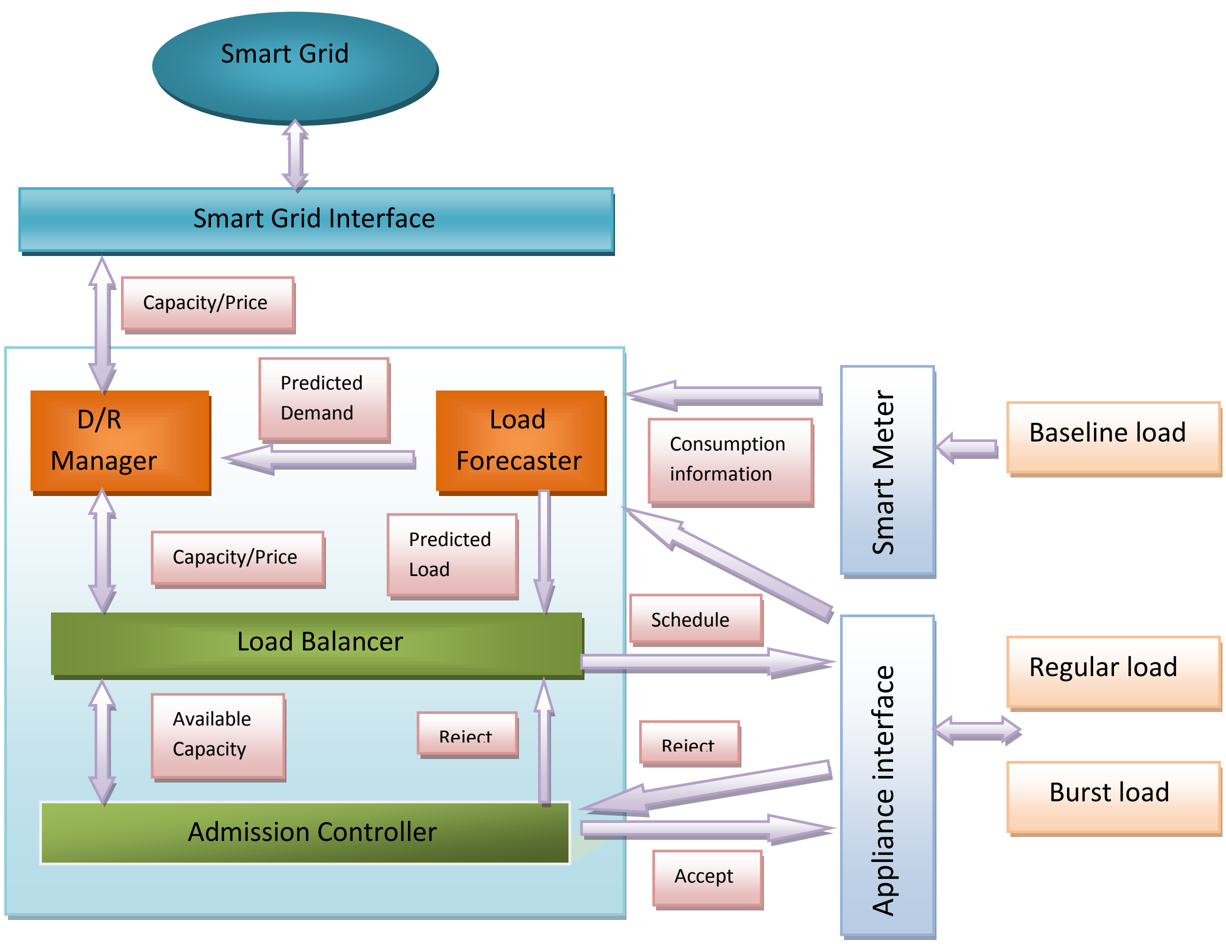


Figure 2.2.4: The proposed system architecture for DSM.

Figure 2.2.4 shows the proposed system architecture of DSM mentioned in [9] which interacts with the appliances and smart grid through interfaces. This architecture for DSM system schedule the load using the multiple time-scale nature where some loads are scheduled in a run time manner in smart buildings. The interface between the energy manager and the appliances works as a middle layer which is used to exchange the information between the energy manager and the appliances. As mentioned earlier, this architecture consists of three layers where the Admission Controller (AC) is the bottom layer which interacts with the appliances for real time load control. It accepts or rejects the appliances requests based on their priority. The Demand Response Manager (DRM) is the upper layer which works with the grid as an interface. The Load Balancer (LB) is the middle layer witch cooperates with the AC and the DRM using optimal load scheduling with respect to the capacity constraints and provides information for taking the benefits from the energy cost and efficient energy consumption. The Load Forecaster (LF) provides the DRM and LB with load forecast.

Some advantages of the layered architectures are given below:

- **Scalability**

  The proposed architecture can be used in buildings, factories, commercial centers, campuses, military bases, and also in micro-grids. Different complexity can be presented among the components but the structure of the system remains the same.

- **Extensibility**

  This structure allows integrating renewable resources and handles the energy storage and exchange. It is also suitable for conventional electricity load management.

- **Composability**

  According to [9], DSM can be implemented for individual consumers or a group of consumers including industrial or commercial purpose. The system is organized in a hierarchical manner so that the price bidding can be carried out at different level.

Chapter 3

Research Methodology

3.1 Model Design

For the simulation experiment, we have considered two different types of thermal appliances, namely AC and refrigerator. The dynamical models for both AC and refrigerator are quite similar to each other. So a dynamical model for refrigerator is adopted from [10] and constructed a dynamical model for AC with some few changes. The dynamical model for both AC and refrigerator is given by:

$$\frac{dT_r}{dt} = \frac{1}{C_r R_r^a}(T_a - T_r) - \frac{A_c}{C_r}\varphi_c$$

Here, C_r is the thermal mass, R_r^a is the thermal resistance, T_r is the chamber temperature, T_a is the ambient temperature, A_c is the overall coefficient performance and φ_c is the power input.

For AC and refrigerator all these parameters are same except the T_r and the T_a . For AC, the T_a is fixed with 28℃ and thus calculate the T_r. In refrigerator, the ambient temperature T_a will come from the AC.

In our Matlab simulation we have used four ACs and two refrigerators where the ambient temperature of all ACs is considered as 28℃ . The ambient temperature of the refrigerators comes from the corresponding rooms temperatures.

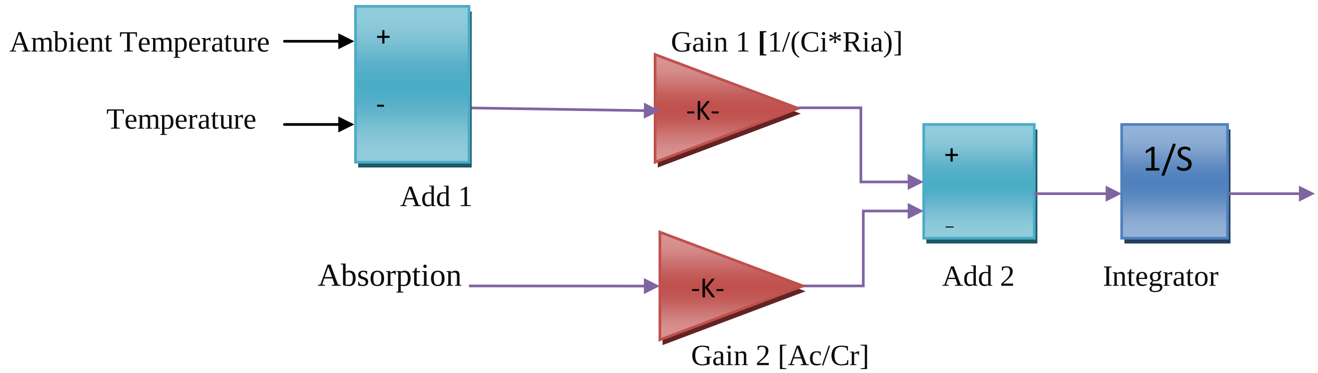


Figure 3.1.1: Thermodynamic Model.

Admission Controller in proposed system architecture mentioned in [9] interacts with the appliances and controls their operations. Depending on the priority and available capacity Admission Controller accepts or rejects the requests of the appliances.

Operations of the appliances are characterized by these four factors:

- Status
- Preemption
- Heuristic value
- Requested power.

A Finite State Machine (FSM) can be used to show the status of an appliance. The status may be:

- **Off State:** Appliance is not enabled.
- **Ready State:** Appliance is enabled and ready to run.
- **Run State:** Appliance is running by receiving command and consumes power.
- **Idle State:** Appliance is stopped and does not receive any command and not consumes power.
- **Complete State:** Tasks is completed and return to the 'Ready State'.
- **Fault State:** Faults in the appliance.

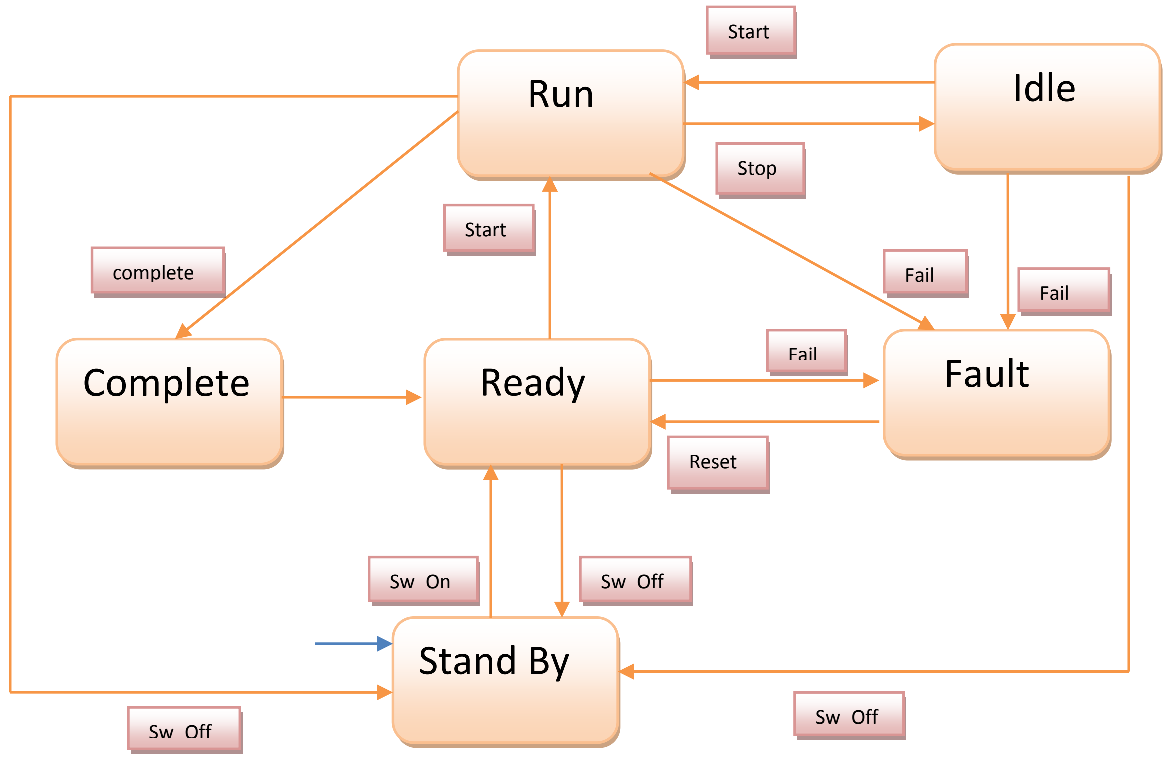


Figure 3.1.2: Appliance Finite State Machine.

Preemption determines whether the tasks of any appliance can be interrupted by other appliance or not. In our work refrigerators are non preemptive and ACs are preemptive.

The priority of the appliances is determined by their Heuristic value. Heuristic value is measured between 0 and 1.

Requested power indicates the power required for an appliance to run.

From our simulation model these four factors of the refrigerator are shown below:

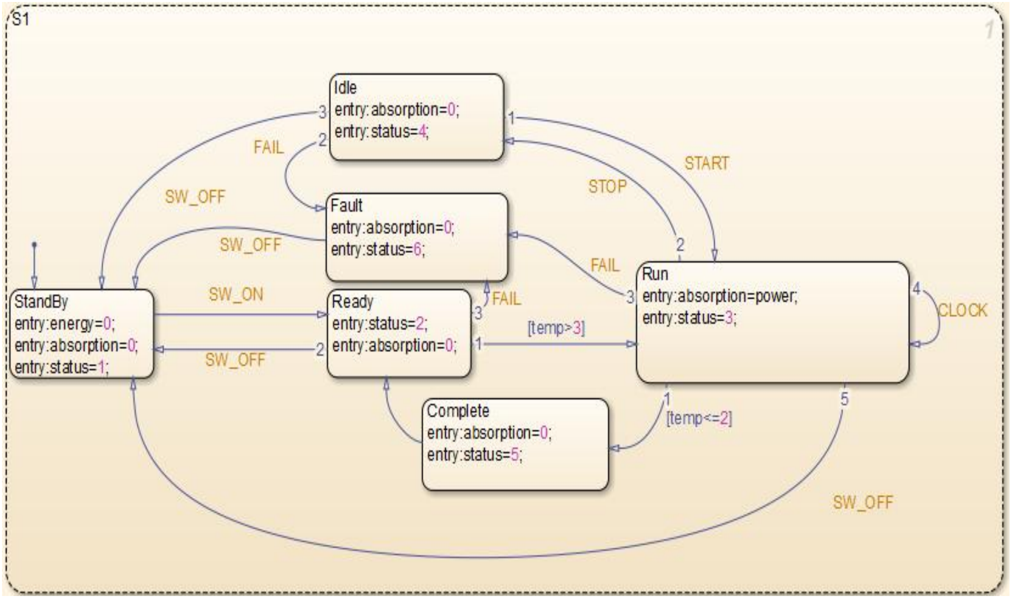


Figure 3.1.3: Admission controller of refrigerator with the stateflow toolbox.

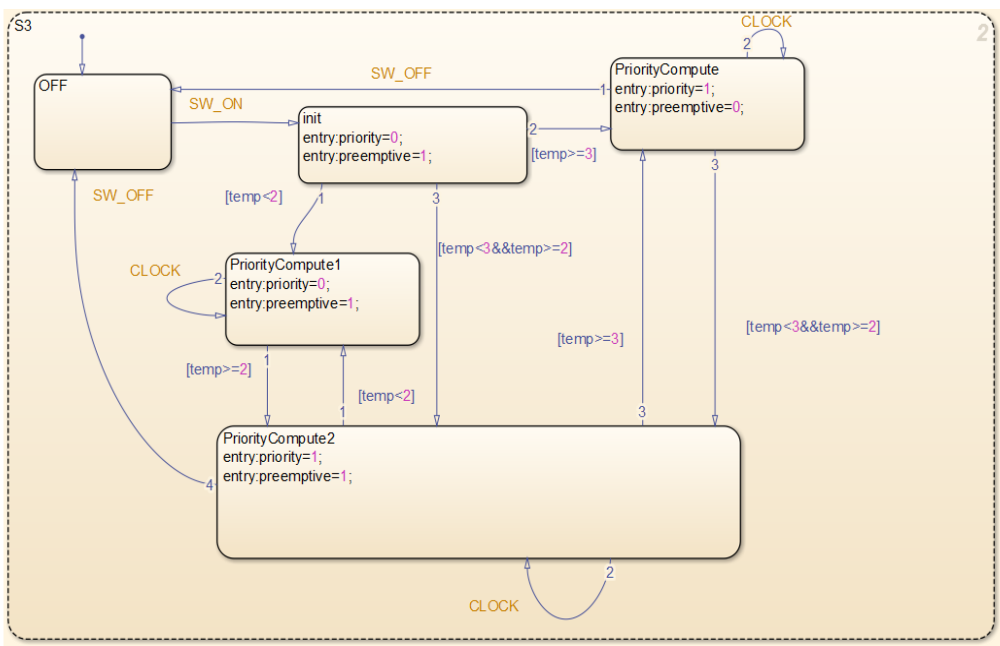


Figure 3.1.4: Preemption and priority computation of refrigerator with the stateflow toolbox.

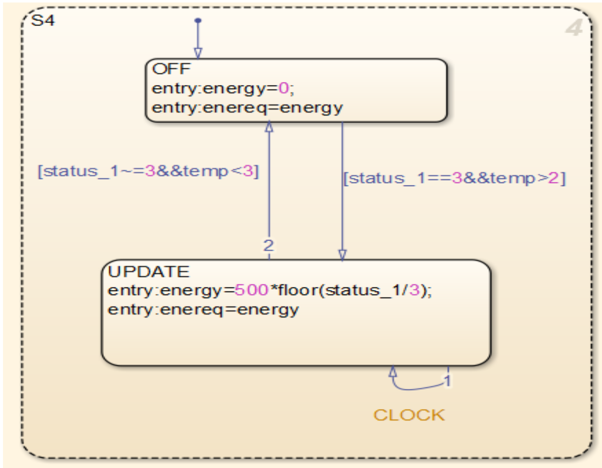


Figure 3.1.5: Requested power computation of refrigerator with the stateflow toolbox.

For AC the four factors are shown below:

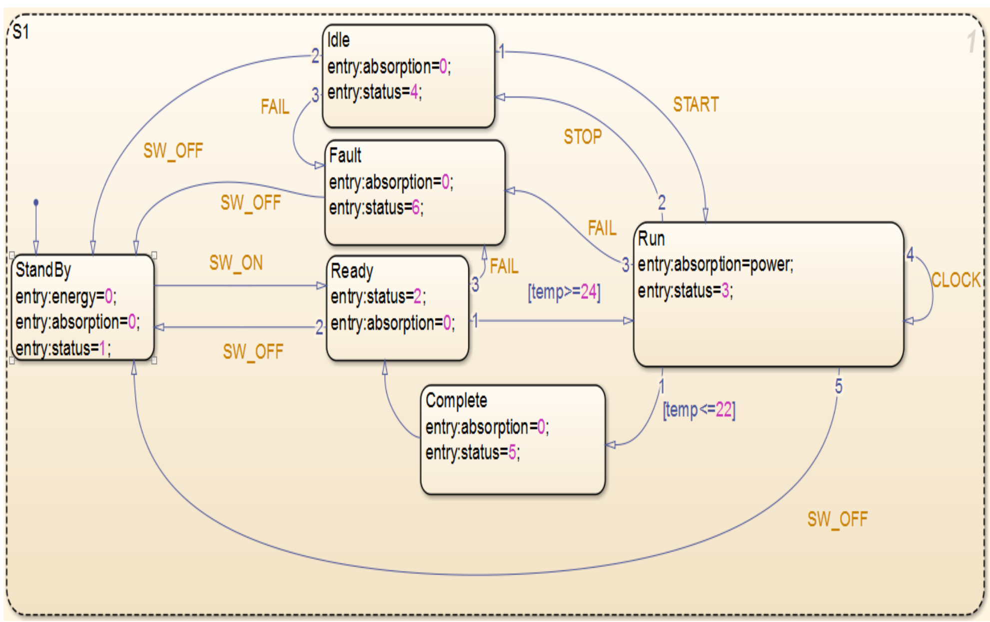


Figure 3.1.6: Admission controller of AC with the stateflow toolbox.

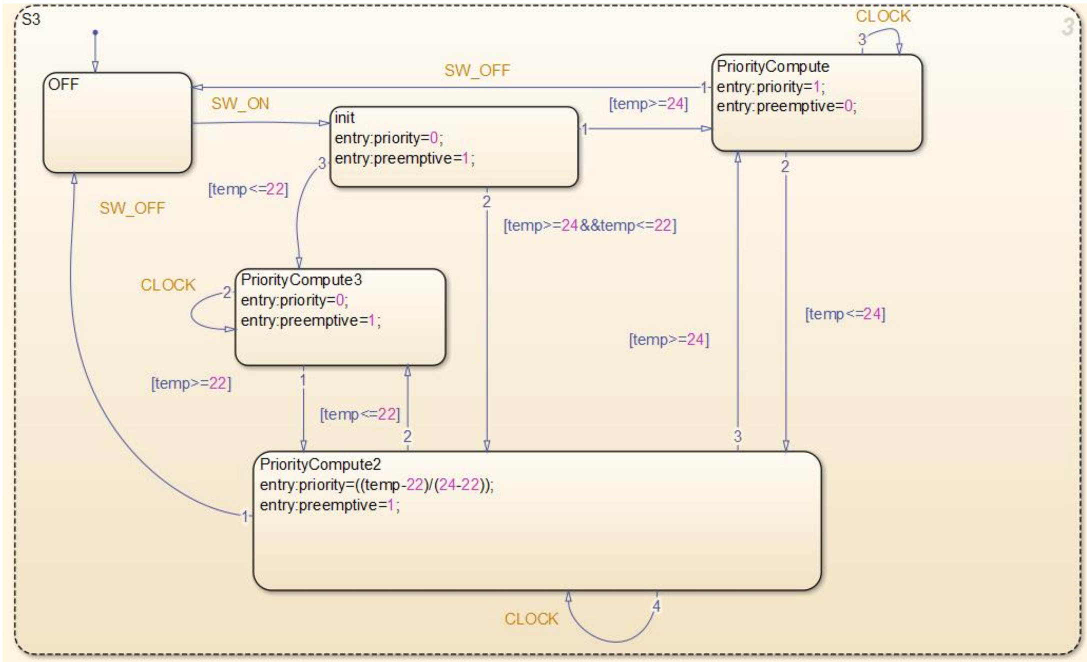


Figure 3.1.7: Preemption and priority computation of AC with the stateflow toolbox.

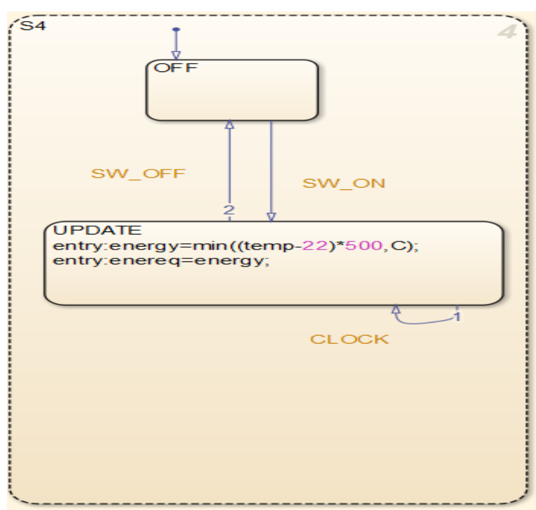


Figure 3.1.8: Requested power computation of AC with the stateflow toolbox.

3.2 Method

In our work we have considered two different types of models. In the first model, the developed algorithm only accepts or rejects an appliance's request based on the available capacity. That means not all the appliances requests can be accepted at the same time. So rejecting an amount of requests causes the inefficient utilization of energy and performance of the appliances.

'Progressive Filling' algorithm has been adopted in this research to solve the following linear problem. Then we have developed our algorithm which distributes the energy power in an efficient way. The problem is:

Here,

$X = \{1, 2..., N\}$; Where a set of N appliances are indexed by X

P_i = Decision variable

$Pmin_i$= Minimum power to request i

Set $t <= P_i$; Where $i \in X$

So $X=\{1,2,...........,N\}$ can be formulated as a liner programming

Now,

max t ;

s.t. $t - P_i <= 0$; Where $i \in X$

$P_i \geq Pmin_i$; Where $i \in X$

$\sum_{i \in X} P_i \leq C$

We have sorted our appliances according to their heuristic value in descending order. Then it distributes the minimum required power to all the appliances to run their operation. In our experiment, we have taken six appliances where there are two refrigerators and four ACs. Refrigerators are non-preemptive. So they will have the highest priority and we cannot interrupt during their operation. So at first they will get their maximum required power if they are

ON/OFF controller. If they are PI controller then they will get their minimum required energy. Then the four ACs will get their power. In our experiment, we have considered the minimum required power of all the ACs as 20% of the required power.

After distributing the minimum required power to the ACs, the remaining capacity can be distributed in many ways. In our work we have considered three different cases through which we can distribute the remaining capacity to the appliances and compare their performances. So that, there are different options available to the consumer who can choose one based on one's requirement. The three different cases are:

- **Distribution in terms of Priority**

As the appliances are sorted in a descending order, the remaining capacity will be distributed to the ACs according to their priority. The AC which has the highest priority will be given the remaining capacity according to its remaining required power. If any capacity remains then the second highest priority AC will get its required power. This process will be continued until the capacity becomes zero.

- **Distribution in terms of Average**

After giving the required power to the refrigerators and minimum power to the ACs we have calculated the average of the remaining capacity for the four ACs. Then distribute the average power to all the ACs.

- **Distribution in terms of Proportionality**

In this case, the remaining power will be distributed according to the ratio of their heuristic values. The proportion of the remaining capacity for each AC is calculated as:

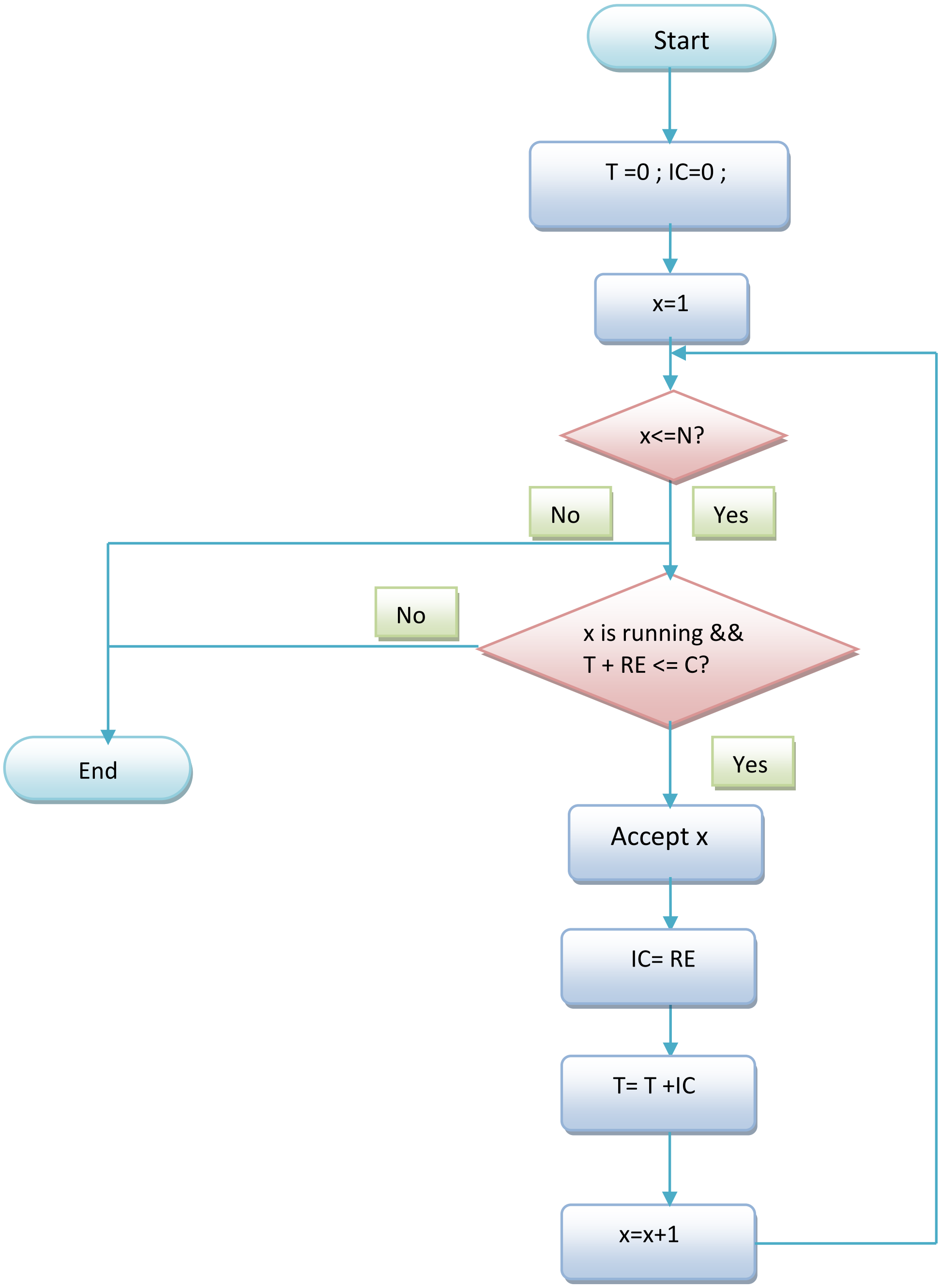
$$Remaining\ capacity * \frac{Heuristic\ value\ of\ each\ AC}{Total\ heuristic\ value}$$

Through our developed algorithm, we can utilize the energy consumption of the appliances efficiently and reduce the wastage of the energy compare to the previous one.

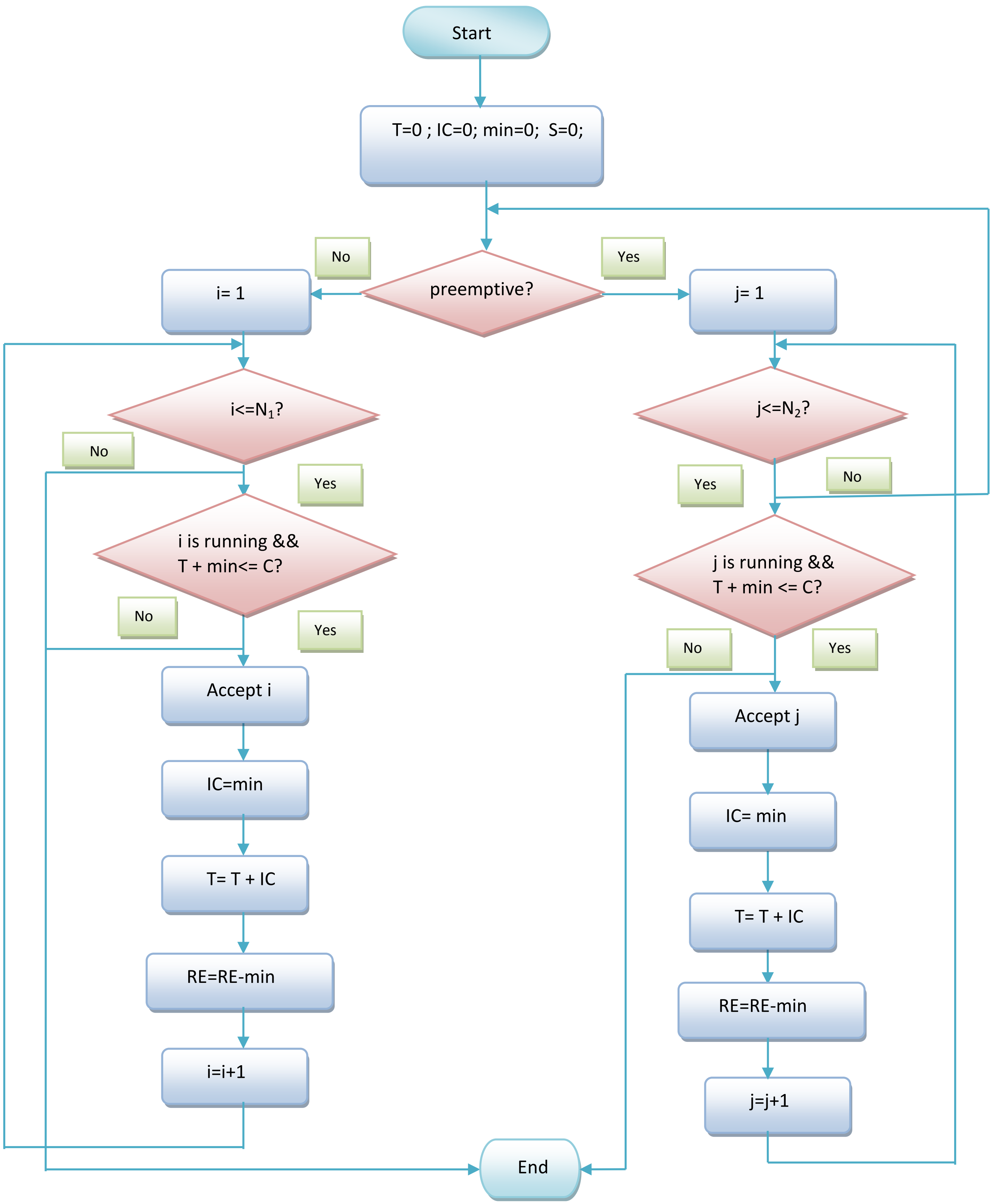
The following flowcharts will show how our model works:

For simplicity we have define the variables in a following way:

- T = Total consumption
- IC = Individual consumption
- RE = Required energy
- min = Minimum required energy
- max= Maximum required energy
- T_ht=Total heuristic value
- ht=Individual heuristic value
- C = Capacity
- rem_C=Remaining capacity
- S= Sum of minimum required energy
- N= Total number of appliances
- x= x^{th} appliance
- N_1= Total number of non-preemptive appliances
- N_2= Total number of preemptive appliances
- i= i^{th} non-preemptive appliance
- j= j^{th} preemptive appliance

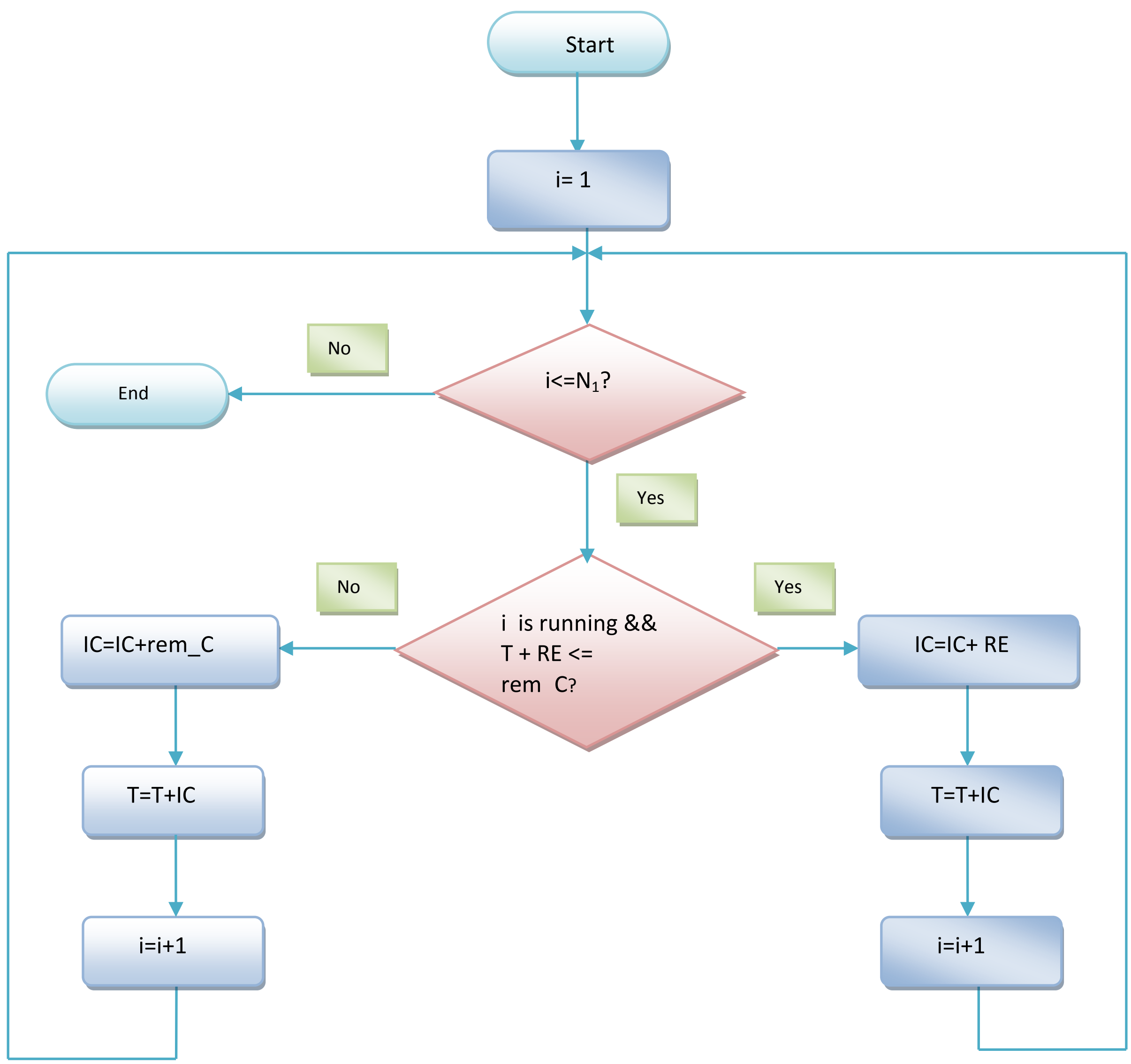


Flowchart 3.2.1: Admission Control [9] of household appliances.

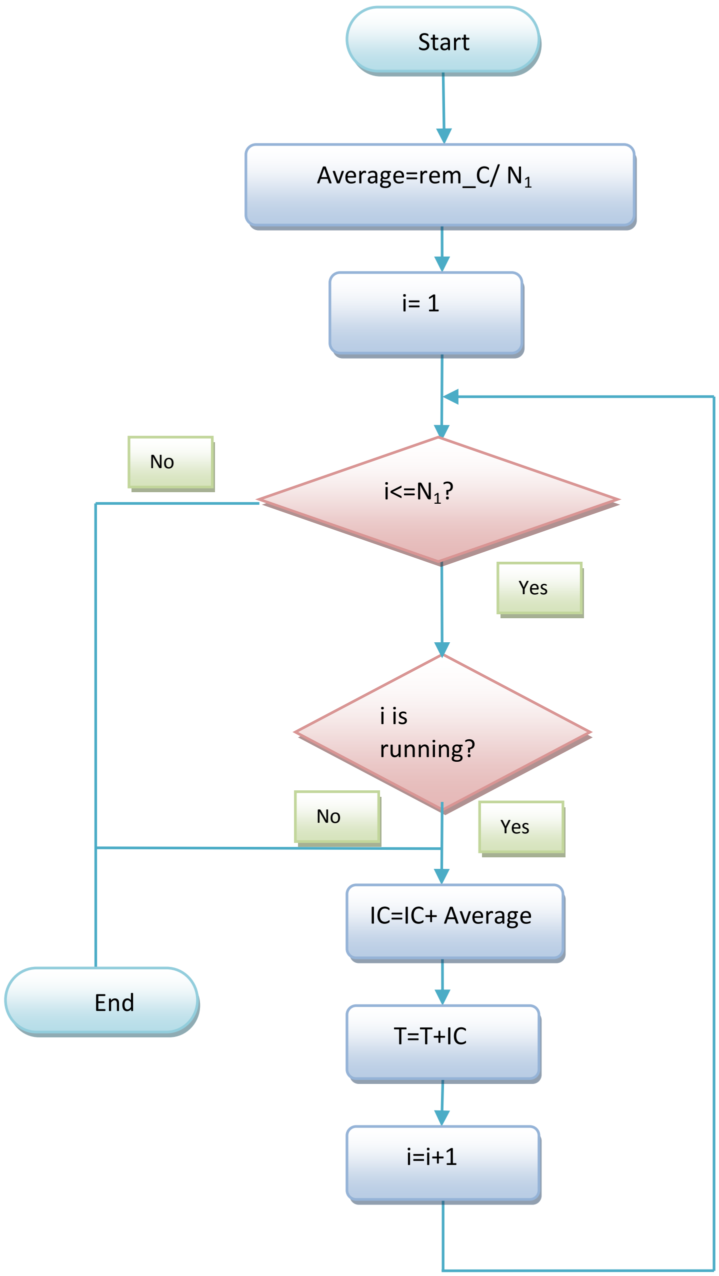


Flowchart 3.2.2: Distribution in terms of minimum required energy.

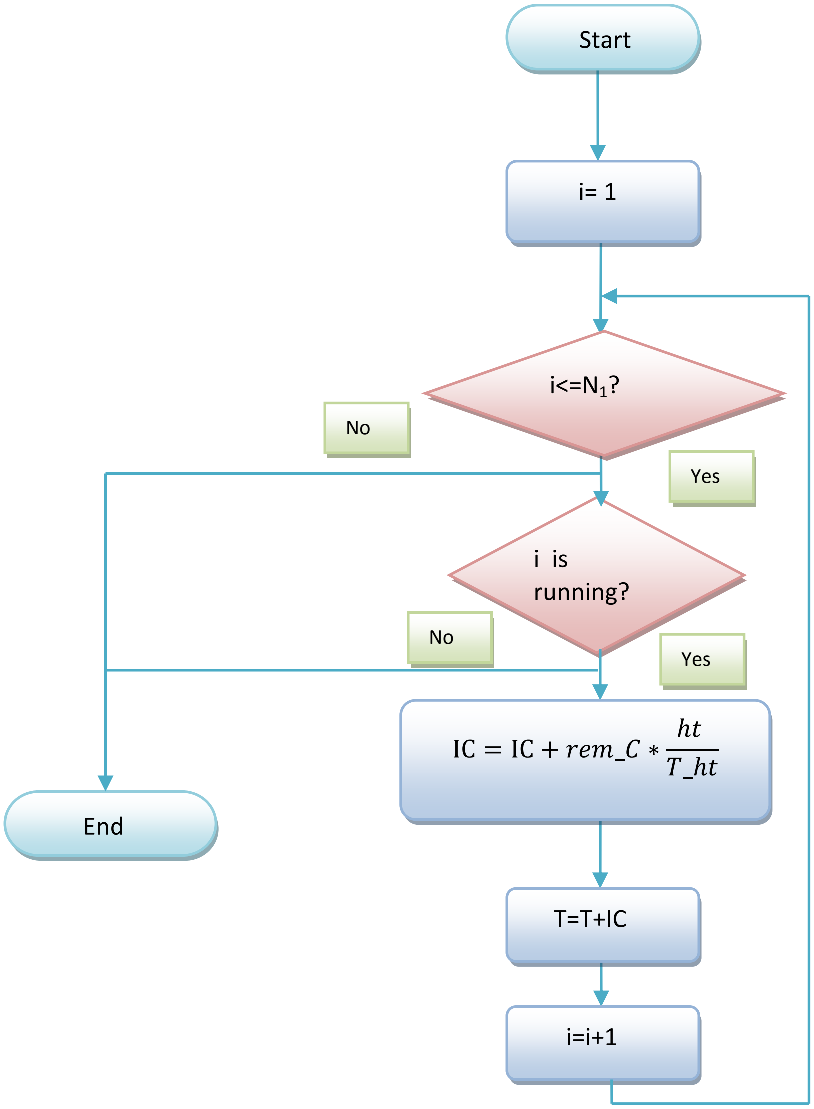
We can distribute the remaining capacity in three cases. The following flowcharts will show the three cases:



Flowchart 3.2.3: Distribution in terms of Priority.



Flowchart 3.2.4: Distribution in terms of Average.



Flowchart 3.2.5: Distribution in terms of Proportionality.

3.3 Algorithm

Variables:

Request Set=X

i= Non-preemptive Request ∈ X

j= Preemptive Request ∈ X

tot_con(i)=Total consumption by the appliances

con(*i*)=individual consumption of appliance *i*

req_energy(i)=individual required energy of appliance i

sum_min=Summation of the lower bound of the appliances

ht= Total heuristic value

ind_ht(*j*) = individual heuristic value of *j* appliance

C=Capacity

rem_c= Remaining capacity

min(*j*)=minimum energy required to run the appliance *j*

Sort the request according to the heuristic value in descending order.

tot_con=0, *con*(*i*)=0, *sum_min*=0

if *C*>=total consumption of appliances **then**

for all *i* ∈ *X* **do**

if the request is running and *tot_con*+ *req_energy(i)*<=C **then**

Accept the request *i*

if request *i* comes from ON/OFF controller **then**

con(*i*)= *req_energy(i)*

tot_con= *tot_con*+ *con*(*i*)

rem_c=C- *con*(*i*)

```
            remove request i from X
        end if
        if request i  comes from PI controller
                con(i)= min(i)
                tot_con= tot_con+ min(i)
        end if
      end if
  end for
 for all j ∈ X  do
     sum_min= sum_min+min(j)
  end for
  for all j ∈ X  do
     if the request is running and tot_con+ min(j)<=C then
            Accept the request j
            con(j)= min(j)
             tot_con= tot_con+ con(j)
             req_energy (j)= req_energy (j)- min(j)
             rem_c=C- con(j)
             remove request j from X
     end if
   end for
end if
```

We can distribute the remaining capacity in three cases:

Case 1: Priority Wise Distribution

for all j ∈ X **do**

if the request is running and *tot_con*+ *req_energy* (*j*)<= rem_c **then**

con(*j*)= *con*(*j*)+ *req_energy* (*j*)

tot_con= *tot_con*+ *req_energy* (*j*)

end if

end for

end if

Case 2: Average Wise Distribution

$$\boldsymbol{avg = \frac{c}{sum\ of\ j\ appliances}}$$

for all *j* ∈ X **do**

if the request is running **then**

con(*j*)= *con*(*j*)+*avg*

tot_con= *tot_con*+ *avg*

end if

end for

end if

Case 2: Proportionality Wise Distribution

for all *j* ∈ X **do**

ht=*ht*+ ind_ht(*j*)

end for

for all *j* ∈ X **do**

if the request is running **then**

con(*j*)= *con*(*j*)+rem_*c**(*ind_ht(j)* /*ht*)

tot_con= *tot_con*+ *con*(*j*)

end if

end for

Chapter 4

Result and Discussion

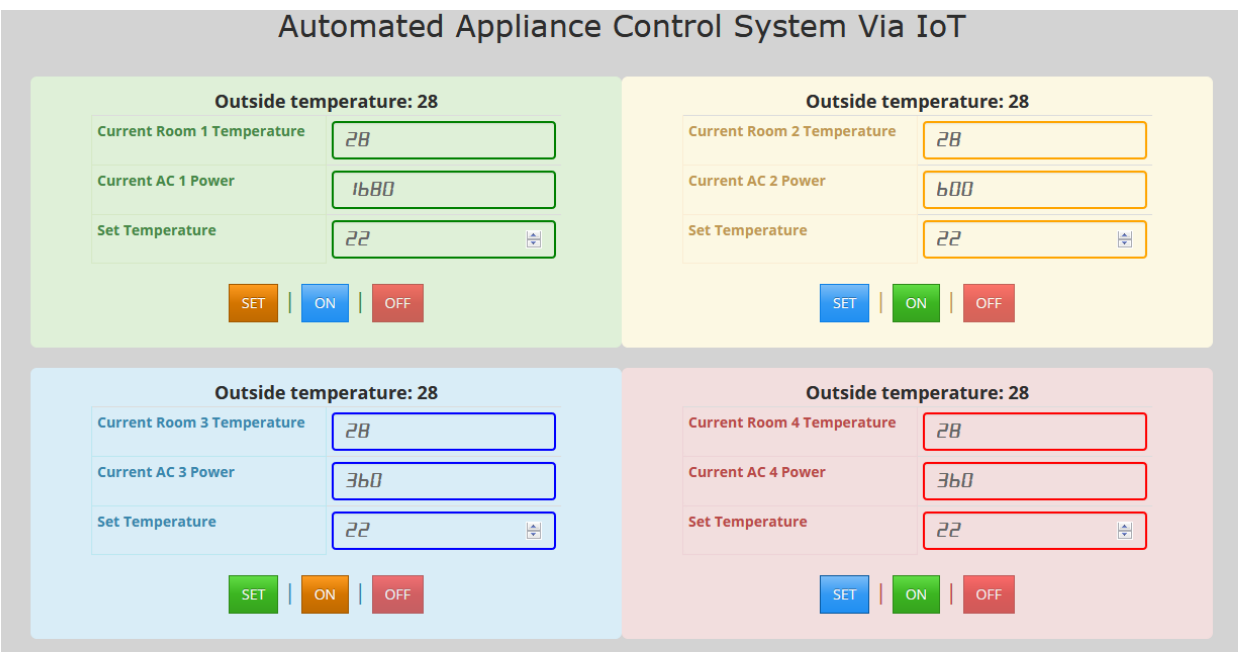
4.1 IOT Experiment

Given below is the IOT based application, where the current room temperature is assumed as 28^{o} Celsius for each room. We have considered the set point of the room temperature is 22^{o} Celsius. Then the power consumption of an individual AC is shown accordingly for the corresponding room.

The data received from the simulation is stored in a local server. Then the data is retrieved from the server to the website designed for this research work.

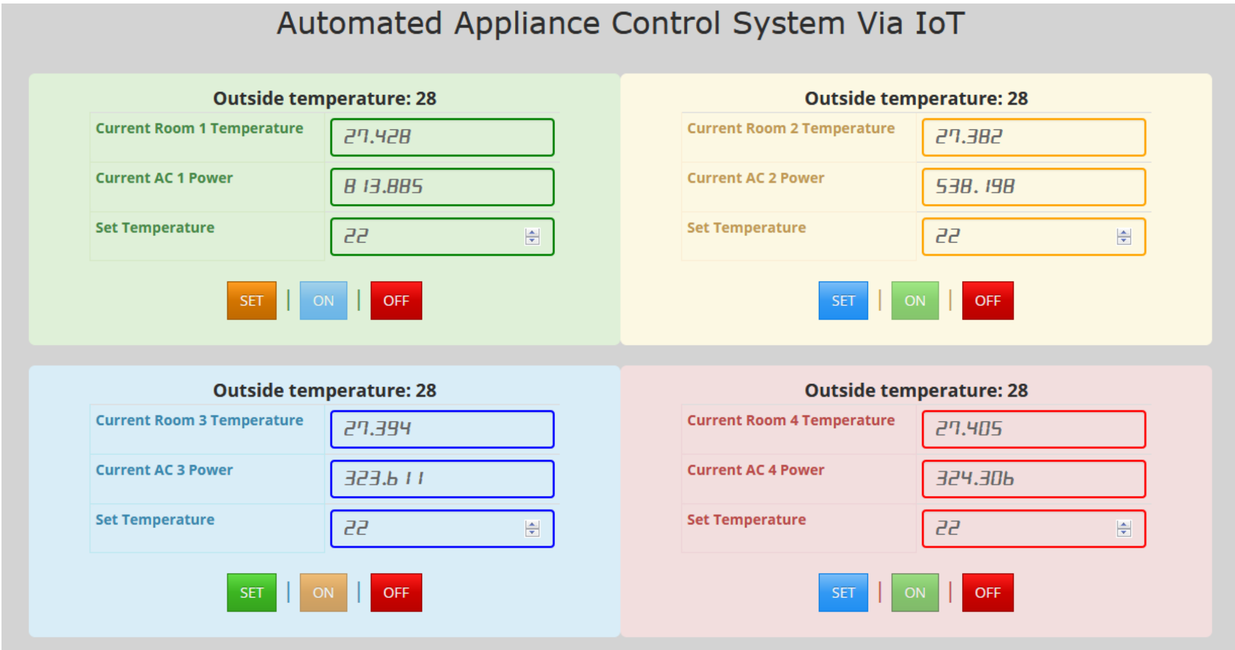
There have three buttons to control the system:

- SET
- ON
- OFF

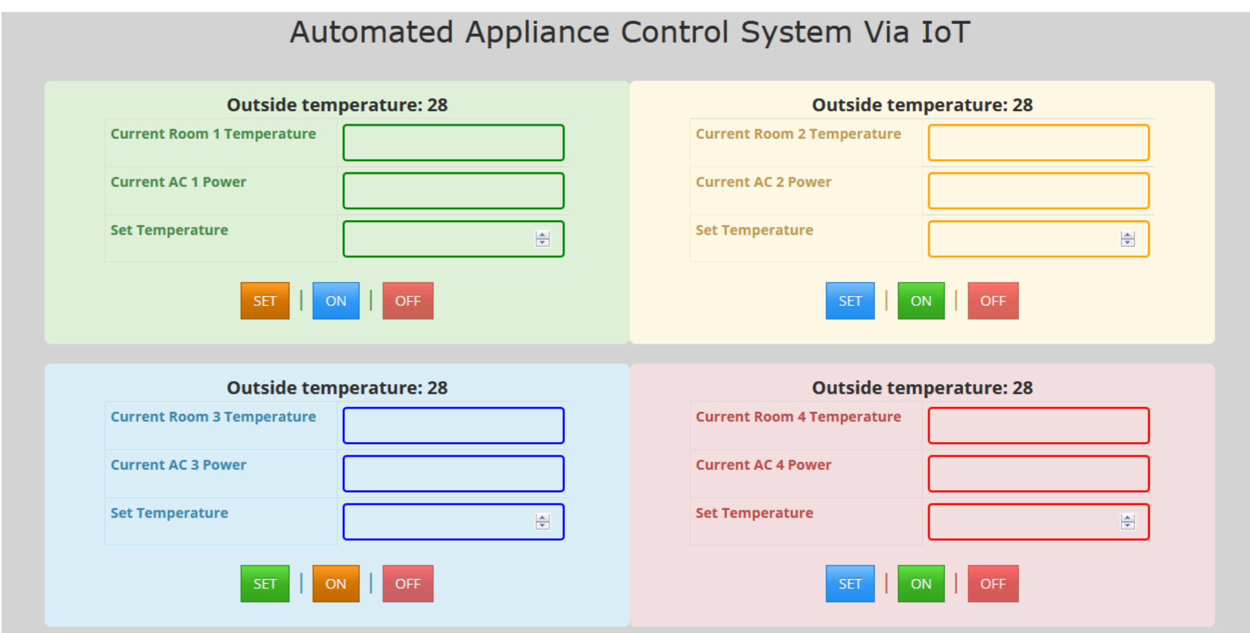


By pressing the “ON” button, ACs start to run and it will show the current room temperature and power consumption with 3 seconds interval. When the temperature decreases from 28^{o}C to 22^{o}C, the power consumption level also decreases from high to low. When the room temperature is

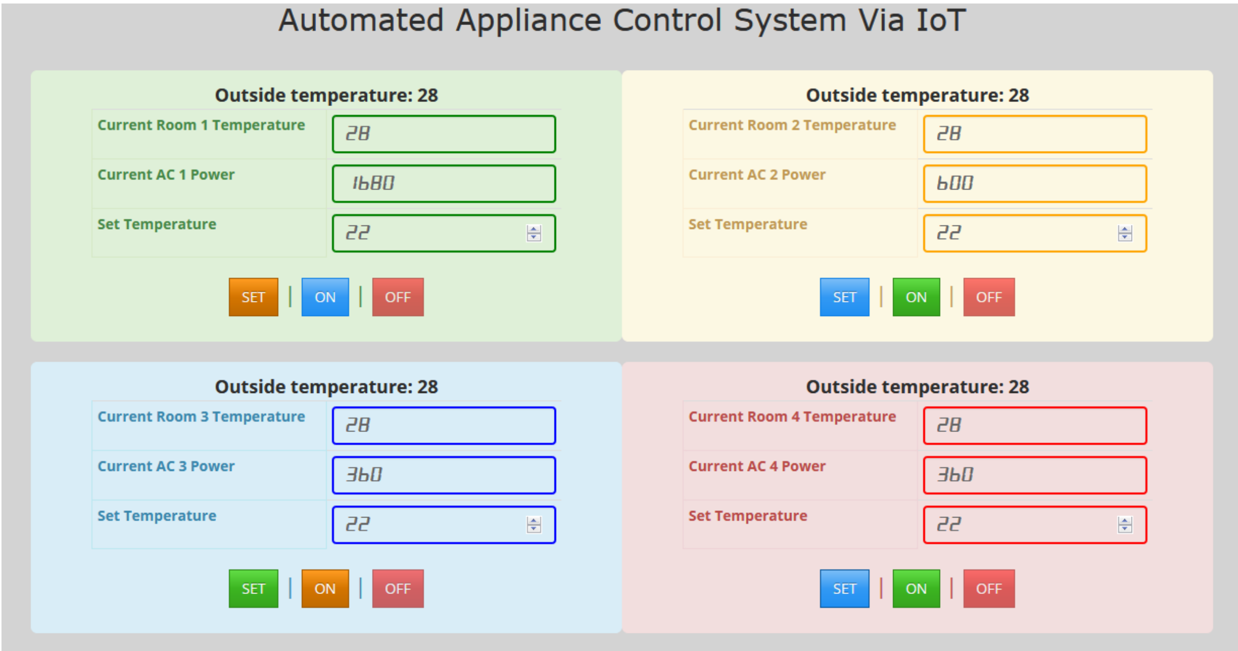
22°C, the relevant power of that AC's become 0 until the temperature is increased to 24°C. Similarly, when the temperature goes down in the range of 24°C to 22°C, the AC started to consume power.



Now if we press the "OFF" button, the system will stop working and room temperature and power won't show in the website. That means the ACs have stop working.



Also pressing the "SET" button, we have set the minimum room temperature 22°C and show current room temperature is 28°C. It will also show the consumed power for that AC.



4.2 Simulation Setup

For our simulation experiment, we have considered a building which has two floors. We have considered three rooms in each of the floor. In first floor, room 1 contains one AC and one refrigerator. Room 2 contains only one AC. This set up is same for the second floor. The ambient temperature for four ACs are fixed to 28℃. The comfort level is defined as $(23 \pm 1)℃$. The ambient temperature of the refrigerator in room 1 of first floor is the corresponding room temperature. Similarly, the ambient temperature of the refrigerator in room 1 of first floor is the corresponding room temperature. We have set the initial condition for the refrigerators as 5℃. Refrigerators are non preemptive so they will turn on when the chamber is 3℃ and turn off when the chamber temperature is2℃.

In our experiment, the heuristic value is measured between 0 and 1. For our refrigerators the heuristic value depends on the maximum and minimum temperature:

- Initially when the chamber temperature is above 3℃, the heuristic value will be 1.
- When the chamber temperature is below 2℃, the heuristic value will be 0.
- When the chamber temperature is below 3℃ and above 2℃, the heuristic value will be 1.

For our ACs the heuristic value is measured by the following formula:

- $Temp_{AC} \geq Temp_{max}$; Heuristic value = 1
- $Temp_{AC} \leq Temp_{min}$; Heuristic value = 0
- $Temp_{max} \geq Temp_{AC} \geq Temp_{min}$; Heuristic value $= \frac{Temp_{AC} - Temp_{min}}{Temp_{max} - Temp_{min}}$

Here, $Temp_{AC}$ is the AC's internal temperature, $Temp_{min}$ and $Temp_{max}$ is minimum and maximum temperature of the comfort zone.

In our experiment, we have considered the maximum required power for both the refrigerators are 500W. If they are ON/OFF controller both the refrigerators will get their maximum required power when the simulation starts. If they are PI controller they will get their minimum required power to run.

We have considered the maximum required power for the ACs in room 1 of both the first and second floor are 3000W. The maximum required power for the ACs in room 2 of both the first and second floor is 1800W. These four ACs will get their power according to the distribution of our algorithm.

4.3 Result and Analysis

We have normalized the time span to 200 time units in our simulation experiment. As we have already mentioned that the maximum required power for refrigerator 1 and 2 are 500W. The required maximum power is 3000W for AC 1 and AC 2 and 1800W for AC 3 and 4. So in worst case, the total maximum power required to accept the six appliances is 10600W. For our analysis the acceptance status, temperatures, total consumption and individual consumptions for different two models are given below:

Model 1: (Without adopting 'Progressive Filling' algorithm)

The first model where admission controller only accepts or rejects based on the available capacity, we have considered the total capacity as 4000W for the first 60 time units. Then we have reduced the capacity limit to 2000W at 60 time steps and to 1500W at 120 time steps. This setup is done to perform the start-up or pre-cooling in off-peak period which resulting less power consumption in on-peak period.

The acceptance status of the six appliances is shown in Figure 4.2.1:

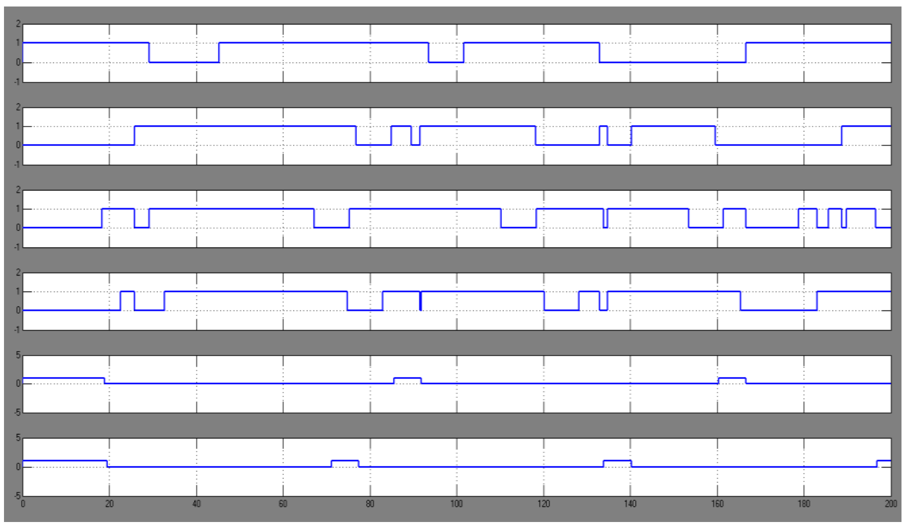


Figure 4.2.1: Acceptance status of the appliances of Model 1

The operational status is indicated by 0 and 1 where 0 and 1 represent the acceptance and rejection respectively. Based on the algorithm only refrigerator 1 and 2 and AC 1 are accepted at the same time where AC 2, 3 and 4 are accepted few times later. This is happened due to the available capacity limit. So all the six appliances requests are not accepted at the same time and they switch more frequently.

The temperature status of the six appliances is shown in Figure 4.2.2:

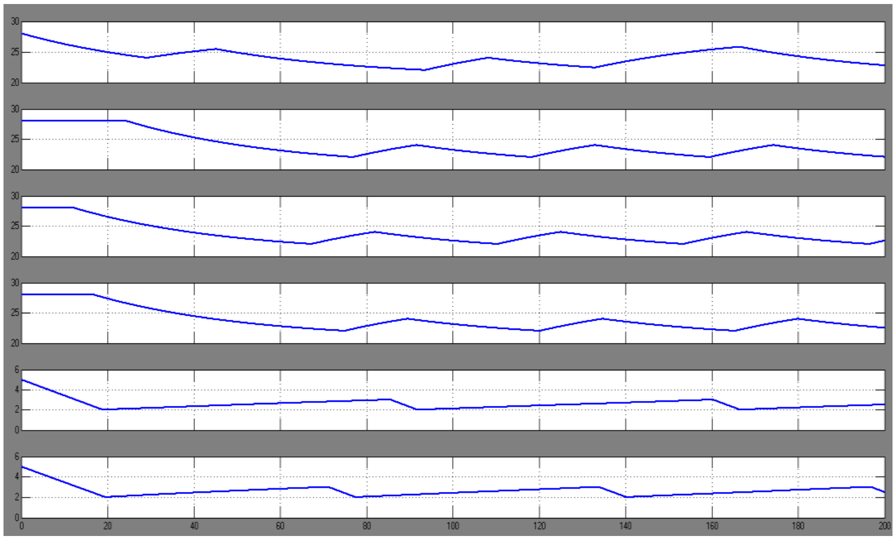


Figure 4.2.2: Temperatures of the appliances of Model 1

The temperature of the refrigerators is always in the range of 2℃ to 3℃. The ACs temperature is not properly maintained in the range of 22℃ to 24℃. There is a slight performance degradation in the ACs temperature because of the shortage of capacity. Since the controller of refrigerators is ON/OFF controller, it consumes the power requested by the refrigerators and due to the lack of capacity, the controller of ACs cannot consume the requested power.

Figure 4.2.3 and 4.2.4 show the total consumption and individual consumptions by the appliances respectively.

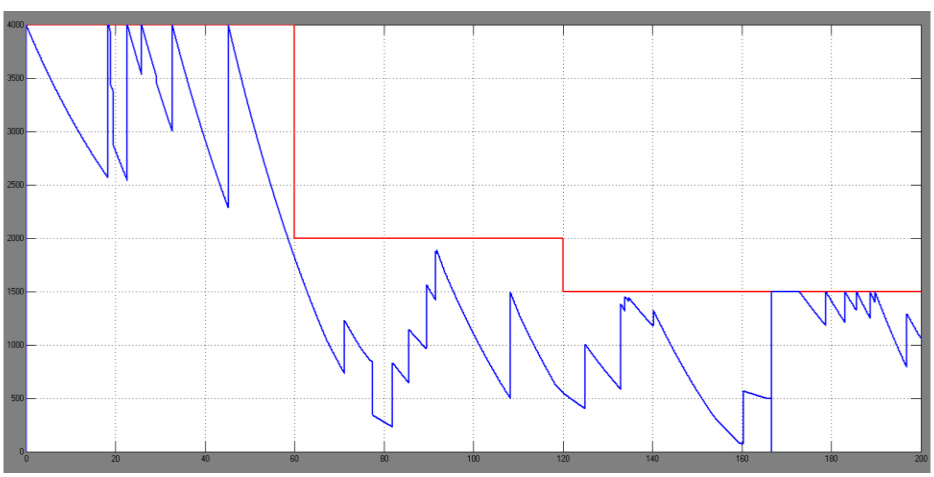


Figure 4.2.3: Total consumption by the appliances of Model 1

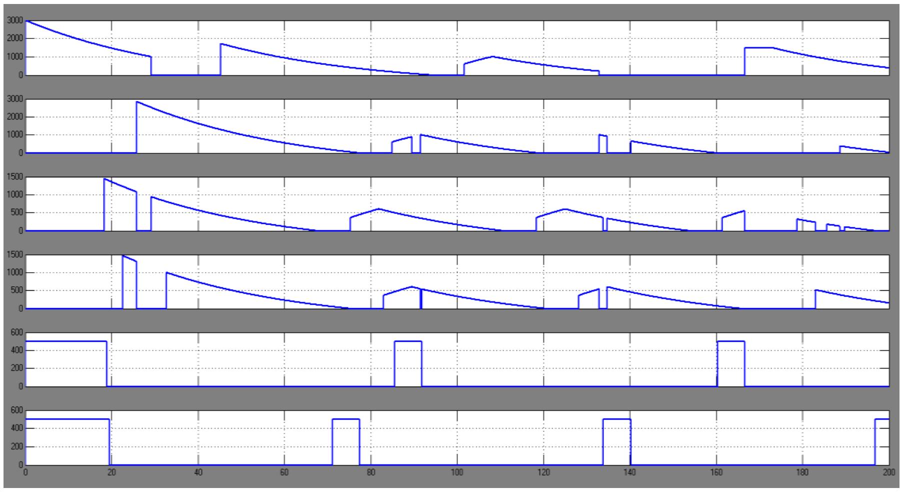


Figure 4.2.4: Individual consumptions by the appliances of Model 1

Figure 4.2.3 shows that all the appliances are not accepted due to the lack of capacity. It is clear that energy is not utilized efficiently. This is justified in the sense that many appliances are rejected because of the less capacity and thus a huge amount of energy is wastage.

Figure 4.2.4 shows the individual consumptions of the appliances where AC 1, refrigerator 1 and 2 are accepted at the beginning and consume power accordingly. Because of capacity limit AC 2, 3 and 4 were rejected first and consumed no power. Later appliances are accepted or rejected according to the available capacity.

Model 2: (Adopting 'Progressive Filling' algorithm)

The experimental setup is similar to the previous one except the capacity limit. We have taken 3000W capacity limit for the first 40 time units which is less than the previous model. Then we reduce the capacity limit to 1500W for up to 120 time units and to 1000W for the remaining time units.

According to our developed algorithm, all the appliances are accepted at the same time. This is reasonable because all the appliances are given a minimum required power to run. This indicates that this model is more efficient than the previous one. After giving the minimum power we have considered three different cases for distributing the remaining capacity as mentioned earlier.

❖ Case 1: Distribution in terms of priority

Figure 4.2.5 shows the acceptance of the appliances where all the appliances are accepted when the simulation starts . It also shows the less frequent switches of the appliances.

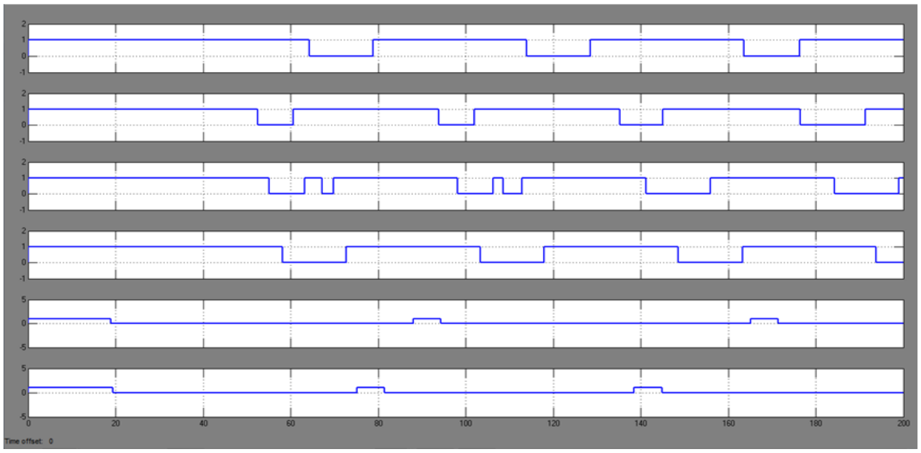


Figure 4.2.5: Acceptance status of the appliances of Model 2 (Case 1)

The temperatures of the appliances are shown in Figure 4.2.6 which shows that the ACs temperatures are in a desired range in most of the time which is 22℃ to 24℃ .

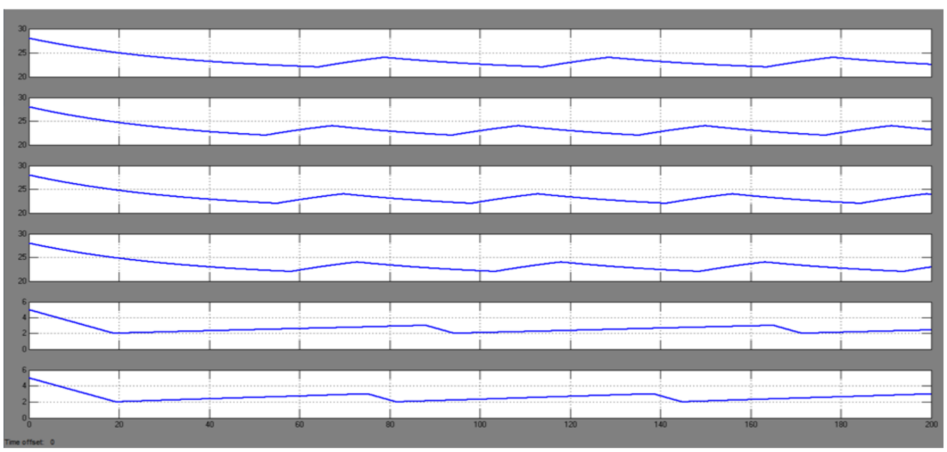


Figure 4.2.6: Temperatures of the appliances of Model 2 (Case 1)

Figure 4.2.7 and 4.2.8 show the total consumption and individual consumptions by the appliances where they consume power according to their priority. It also shows the more proper utilization of energy than the previous model.

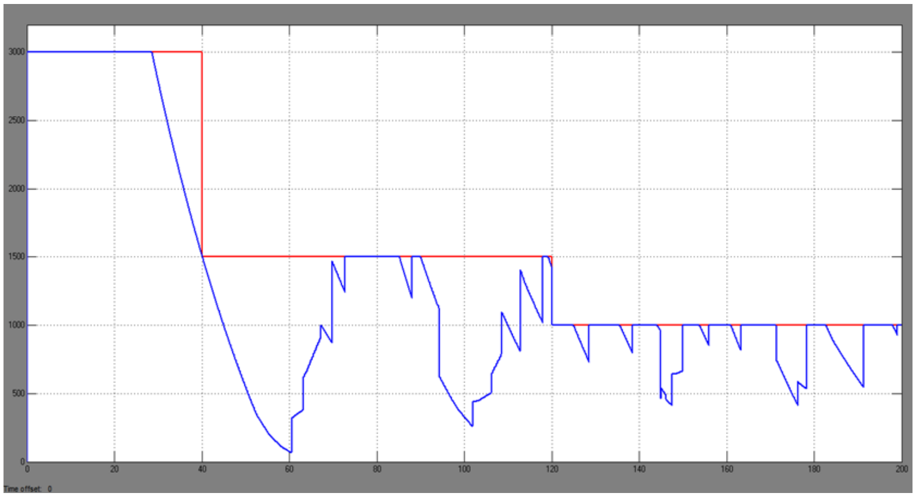


Figure 4.2.7: Total consumption by the appliances of Model 2 (Case 1)

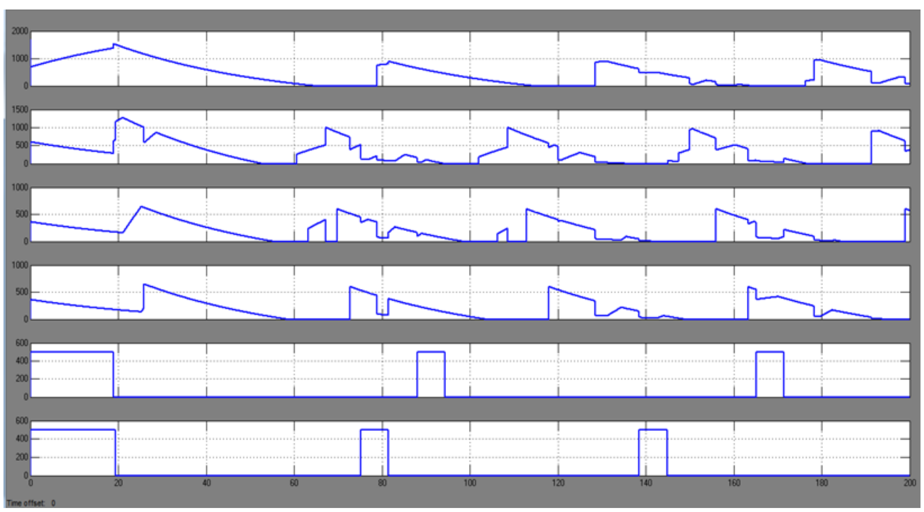


Figure 4.2.8: Individual consumptions by the appliances of Model 2 (Case 1)

❖ Case 2: Distribution in terms of average

Figure 4.2.9, 4.2.10 show the acceptance status and temperatures of the appliances which show less switches and desired temperature ranges more efficiently of the applainces than the previous model.

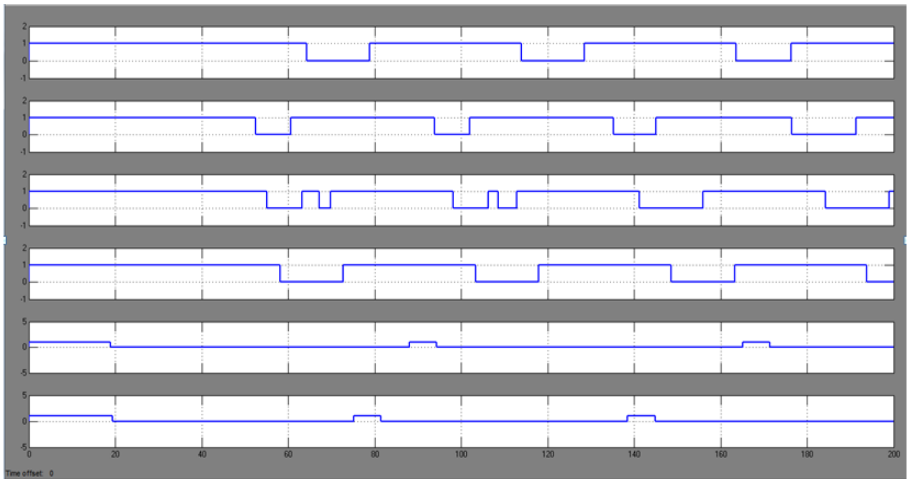


Figure 4.2.9: Acceptance status of the appliances of Model 2 (Case 2)

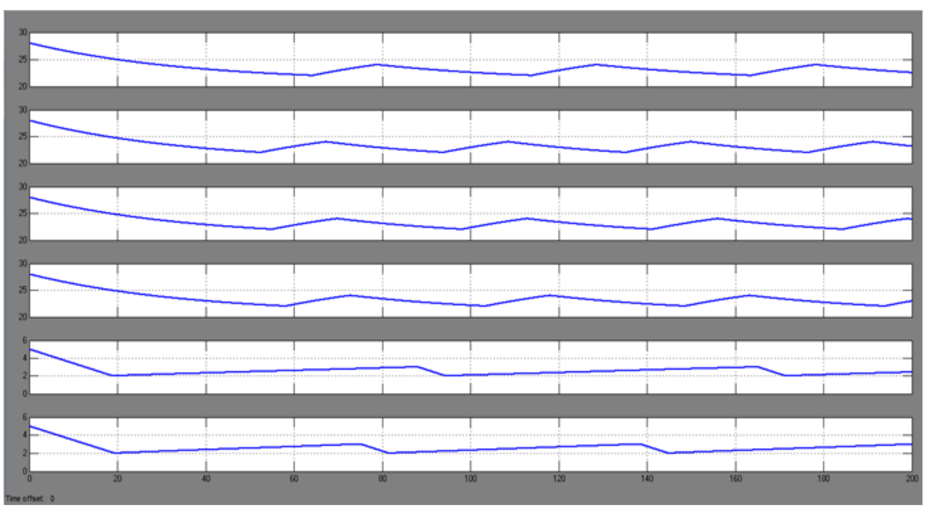


Figure 4.2.10: Temperatures of the appliances of Model 2 (Case 2)

It is clear from Figure 4.2.11 that the total consumptions by the appliance in Case 3 shows more effective use of energy than the Case 1 and 2. Figure 4.2.12 shows the individual consumption by the appliances in this case.

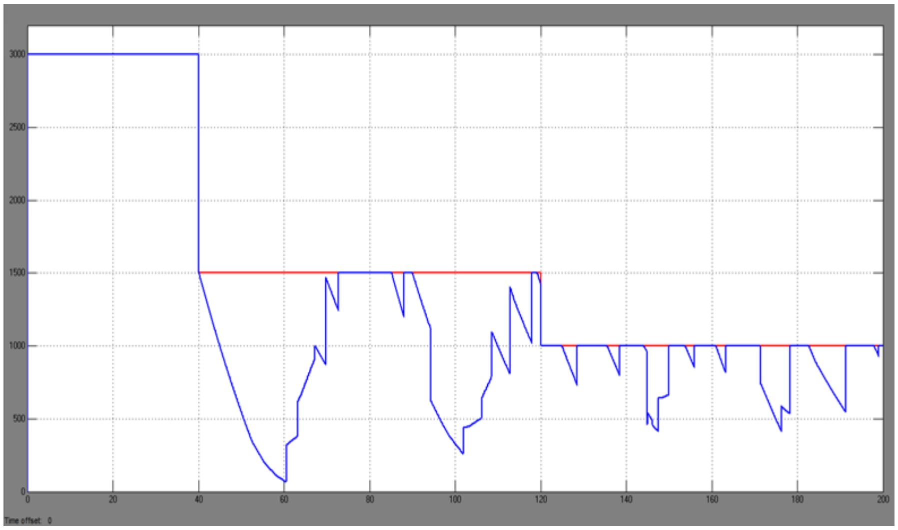


Figure 4.2.11: Total consumption by the appliances of Model 2 (Case 2)

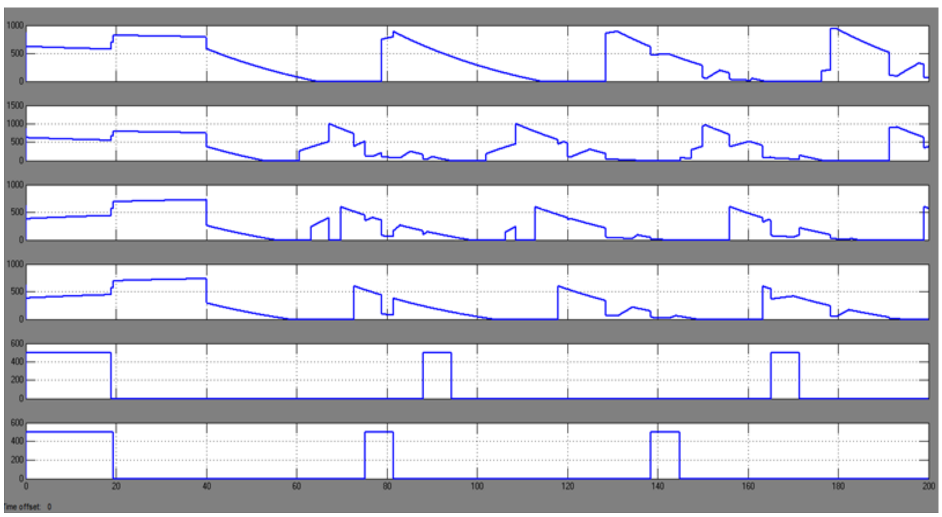


Figure 4.2.12: Individual consumptions by the appliances of Model 2 (Case 2)

❖ **Case 3: Distribution in terms of proportionality**

Figure 4.2.13, 4.2.14, 4.2.15 and 4.2.16 show the acceptance status, temperatures, total consumption and individual consumptions by the appliances. This case is more effective use of energy utilization than the previous model but less effective than Case 1 and 2.

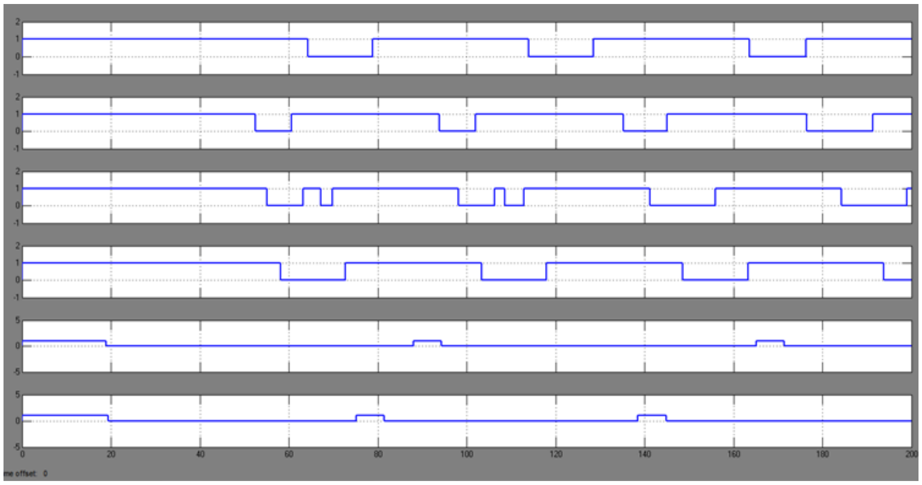


Figure 4.2.13: Acceptance status the appliances of Model 2 (Case 3)

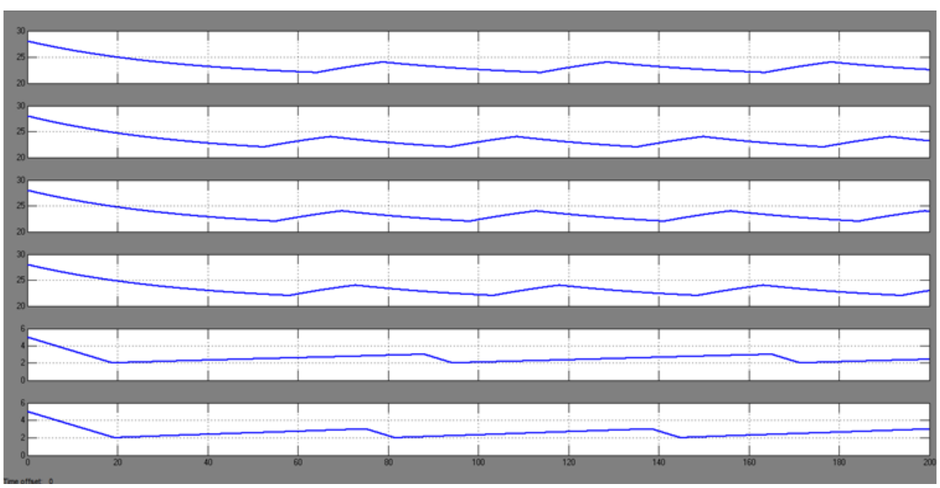


Figure 4.2.14: Temperatures of the appliances of Model 2 (Case 3)

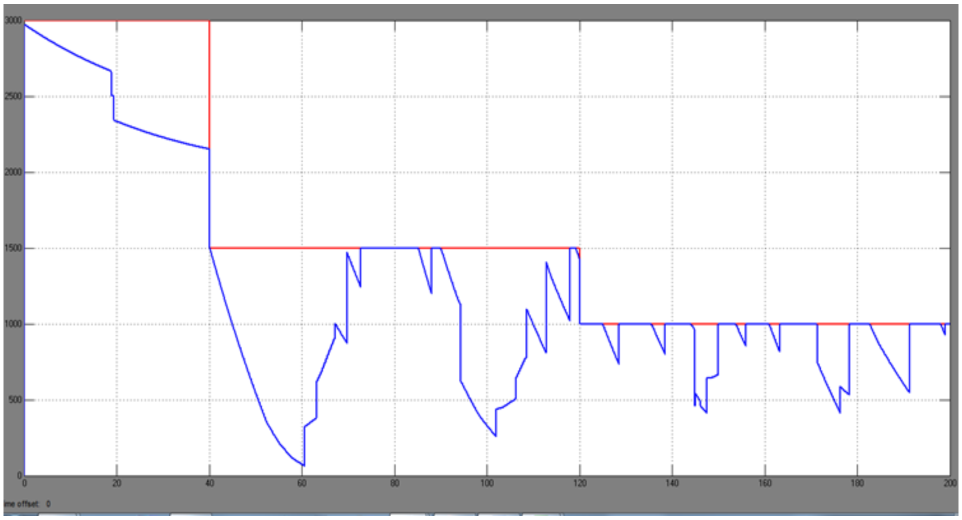


Figure 4.2.15: Total consumption by the appliances of Model 2 (Case 3)

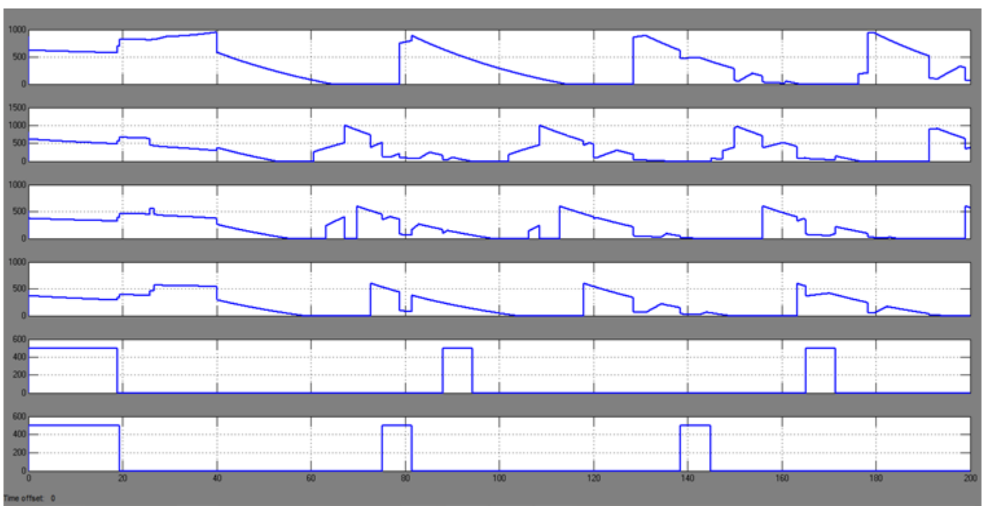


Figure 4.2.16: Individual consumptions by the appliances of Model 2 (Case 3)

To that end, we can say that Model 2 is more effective than Model 1 where all appliances can run their operations and utilize the available power efficiently with a given limited capacity. In addition, Case 2 shows more effective distribution of remaining capacity than that of Case 1 and 3 in Model 2.

Chapter 5

Conclusion

5.1 Overall Conclusion

We have adopted ‘Progressive Filling’ algorithm in our research and compared with the result shown in [9] for the admission controller. The previous algorithm shows only the acceptance and rejection of the appliances where the utilization of energy is inefficient. The proposed model considers three different cases which show the efficient distribution of power among the appliances with a given capacity. The simulation results show the effectiveness of the models compare to the algorithm proposed in [9]. Using IoT one can give command to the system and control the operations of the appliances from anywhere of the world. So there are different options to choose dependent on individual scenario and developed such a system according to the requirement.

5.2 Future Works

- **Work with the upper layers:**

In our research, we work only with the lower layer (Admission Controller) of the proposed system architecture. So we hope that in future, we will work with the upper layers of the architecture.

- **Work on generation side:**

Our research is only limited to consumer side demand management. So our main challenge is to work with the smart grid which is concerned with different technologies and system. Power generation, power transmission, efficient distribution and power consumption with less energy wastage are big challenges here. We can cope the above in the future research.

- **Trade-off between the grid and consumer side:**

Grid wants to get the benefit of its power generation, distribution etc where consumers want to consume energy with less cost. So, it would also be an interesting topic for the future research.

- **Implementation of the work:**

The proposed work is implementable. So we will extend our research to create an environment where the proposed work can be implemented. So we can verify the feasibility of this work in practical scenario.

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