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Effect of Selected Parameters on the Cost of Energy for a Model House using Multiple Energy Sources

Anjum Ali[1], Abdul Rauf[2]

[1,2]National University of Computer and Emerging Sciences, Lahore, Pakistan

ABSTRACT

This paper presents the results obtained by studying the effects of variation of selected parameters on the cost of energy consumed in a model house. The model house was designed as part of the C.A.S.E.[1] project. The objective is to provide desired climate conditions inside the house using one of the available energy sources based on the control algorithm developed for the embedded control module. Simulation results from MATLAB are included as part of the paper.

Keywords: Solar photovoltaic panels, solar thermal collectors, flat-bed collectors, wind energy, renewable energy.

I. INTRODUCTION

The energy crisis in Pakistan appears to continue for the next few years. One of the problems faced by an ordinary citizen is "load shedding", which becomes worse during extremely hot or extremely cold days. Short term solutions have been used by many people to solve the problem on a local basis. However, there appear to be many weaknesses associated with such solutions, for example, inefficient use of different energy sources, lack of awareness of the strengths and weaknesses of such solutions, and the inability to match the appropriate source of energy with the requirements. The results of a study performed on a "model house" that was developed as part of an EE senior design project at the National University of Computer and Emerging Sciences, Lahore, Pakistan, has been presented and discussed in this paper. The various sources of energy available to the model house are energy from solar photovoltaic panels, energy from solar thermal collectors, wind energy, electricity from the national grid and natural gas. The national grid in Lahore, Pakistan, is managed by a company called Lahore Electric Supply Corporation, or LESCO. All the sources of energy are generally not available at all times during the day, and for all months during the year. Simulation results using MATLAB have been included and discussed. Since the model is scalable, the results can be extended to larger houses or even commercial buildings.

II. THE C.A.S.E. MODEL HOUSE

Figure 1 shows the picture of the model house developed as part of the C.A.S.E. project.

Fig. 1: Picture of the model house

[1]The project was named "Considering Alternate Sources of Energy", or C.A.S.E. This project won the National Grassroots ICT Research Initiative (NGIRI) grant of Rs. 85,000/= from the National ICT R&D Fund during Fall 2013.

The model house has been designed with sub-systems to provide desired climate conditions inside the house by using the optimum source of energy available at a given time. It includes a solar panel connected through a charge controller to a lead acid battery, called S. A wind turbine is connected through a dynamo to another battery, called W. The power from LESCO is connected to a third battery, called L, through a battery charger. Two types of flat bed collectors (FBCs) [1]-[4], one using a copper tube and another using galvanized iron (GI) pipes, were designed to heat water at times of bright sunlight. These are shown in Figure 2 and Figure 3 respectively. This water can be used in various appliances within the model house. In case the hot water from the FBC is not available, a water heater using natural gas can be used to provide the needed hot water to the appliances. The selection between water from the flat bed collector and the natural gas water heater is done by energizing one of the solenoid valves, labeled F or G.

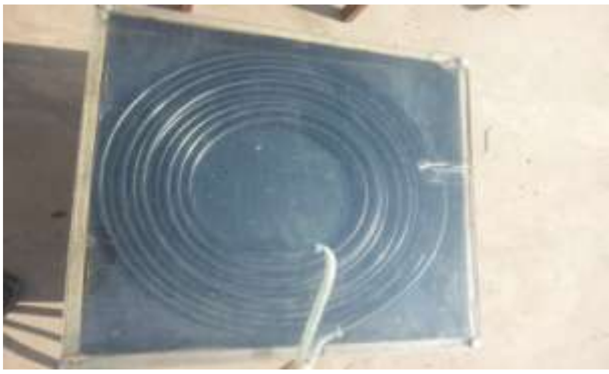

Fig. 2: Flat bed collector using a copper tube

Fig. 3: Flat bed collector using GI pipes

A detailed block diagram of the various components mentioned above is shown in Figure 4. The model house is scalable, which means that specifications and size of the various components can be changed if desired. The energy consuming loads in the model house include a fan, a ventilator, an air conditioner, a room heater and a humidifier.

The brain of the model house is a PIC18F452 microcontroller based Embedded Control Module (ECM), which attaches one of the available sources of energy to the load(s) in the house according to the control algorithm designed as part of the project. Figure 5 shows the flowchart of operation of the controller. Humidity checks are not shown on the flowchart to avoid clutter. The control algorithm driving the ECM is listed in Figure 6. The cost of energy will also be linked with the control algorithm. Since the control algorithm for the system has been designed to provide optimum climate conditions inside the house, the cost of energy consumed may not be the minimum at all times during the day, and for all days during the year.

Optional peripherals, like a matrix keypad, an LCD display, or a hexadecimal display, can be attached to the ECM if and when desired. The connections are shown in Figures 7, 8 and 9 respectively.

III. CONSTRAINTS AND ASSUMPTIONS

The study presented in this paper is based on the constraints and assumptions mentioned in the next few paragraphs.

All appliances operate at 220 volts AC, either directly on LESCO, or on batteries using a 12 VDC–220VAC sine-wave inverter. However, the room heater cannot be operated on the inverter. Instead, when LESCO is not available, the room heater can be operated on natural gas. The air conditioner can be operated only on LESCO because of its high current demand. It is also assumed that if LESCO is available, it can be supplied directly to all loads. Simultaneously, the battery L is charged to voltage V_L. The solar panel charges battery S through the charge controller, while the wind turbine charges the battery W through the dynamo. The voltages across battery S and W at any time are denoted by V_S and V_W respectively. The availability of a particular source is indicated by the corresponding battery voltage being the highest. A complete list of symbols used in this paper is given in Table I.

TABLE I. COMPLETE LIST OF SYMBOLS USED

Symbol	Meaning
T_p	Temperature of the water in the pipes of the flat bed collector
T_e	Temperature of the environment outside the house
T_r	Present temperature inside the house
T_{hi}	High limit for the temperature to be maintained inside the house
T_{lo}	Low limit for the temperature to be maintained inside the house
V_L	Voltage of the battery connected to LESCO
V_S	Voltage of the battery connected to the solar panel
V_W	Voltage of the battery connected to the wind turbine
U_e	Humidity of the environment outside the house
U_r	Present humidity inside the house
U_{hi}	High limit for the humidity to be maintained inside the house
U_{lo}	Low limit for the humidity to be maintained inside the house
W_{hi}	High limit for the temperature of the hot water needed for the appliances
W_{lo}	Low limit for the temperature of the hot water needed for the appliances
E_A	Energy cost using air conditioner, in PKR
E_F	Energy cost using a fan, in PKR
E_H	Energy cost using heater, in PKR
E_U	Energy cost using humidifier, in PKR
E_V	Energy cost using ventilator, in PKR
E_T	Total energy cost, in PKR

A mist type humidifier is used to spray water droplets, thereby increasing the humidity in the room, but it cannot be used to decrease the humidity. The air conditioner has to be used for this purpose. During the summer months, the heater is not used. The cost of natural gas used for heating the water is assumed to be negligible. Moreover, the flat bed collector does not have an operating cost. The assumed rating of various appliances in kilowatts is given in Table II and the assumed cost in Pak. rupees per kilowatt hour (PKR/kwH) for various sources is listed in Table III.

TABLE II. RATINGS OF VARIOUS APPLIANCES

DEVICE	SYMBOL	RATING (KW)
AIR CONDITIONER	RA	5.0
FAN	RF	0.1
HEATER	RH	1.5
HUMIDIFIER	RU	0.4
VENTILATOR	RV	0.15

The hourly cost of solar energy, does not include initial cost of setting up the system. Temperature and humidity data inside the model house has been taken at the interval of one hour. However, this interval can be increased or decreased as desired. In order to keep the discussion simple and understandable, the losses associated with conversion from one form of energy to the other are assumed to be negligible.

TABLE III. COST OF USING DIFFERENT SOURCES

SOURCE OF ENERGY	SYMBOL	COST (PKR/KWH)
MAIN LESCO SUPPLY	CM	10
BATTERY CHARGED WITH LESCO	CL	13
BATTERY CHARGED WITH SOLAR PANEL	CS	6
BATTERY CHARGED WITH WIND TURBINE	CW	8
EQUIVALENT COST OF NATURAL GAS	CG	6

IV. COST EQUATIONS USED IN MATLAB

// When Air Conditioner (AC) is in use

Te>Tr and Tr>Thi:
E_A=
IF LESCO = 1, = C_M*R_A
IF LESCO = 0, = 0 //can't use AC

// when Fan is in use
Te>Tr and Tr>Thi
E_F=
IF LESCO = 1, use AC so E_F=0

IF LESCO = 0, & IF $V_S > V_W$, V_L, = C_S*R_F
& IF $V_W > V_S$, V_L, = C_W*R_F
& otherwise = C_L*R_F

// when Humidifier is in use
Hr<Hlo
E_U =
IF LESCO = 1, = C_M*R_U
IF LESCO = 0, & IF $V_S > V_W$, V_L, = C_S*R_U
& IF $V_W > V_S$, V_L, = C_W*R_U
& otherwise = C_L*R_U

// when Ventilator is in use
Te<Tr and Tr>Thi
E_V=
IF LESCO = 1, = C_M*R_V
IF LESCO = 0, & IF $V_S > V_W$, V_L, = C_S*R_V
& IF $V_W > V_S$, V_L, = C_W*R_V
& otherwise = C_L*R_V

// when Heater is in use
Te<Tr and Tr<Tlo
E_H=
IF LESCO = 1, = C_M*R_H
IF LESCO = 0, = C_G*R_H

// Total cost

$E_T = E_A + E_F + E_H + E_U + E_V$

V. SIMULATION RESULTS

Figures 10-21 show the total cost of energy consumed versus load shedding for all the months of the year 2014 for Lahore, Pakistan. The cost of energy is also dependent on the control algorithm governing the embedded control module (ECM). Maximum and minimum temperatures for all the days of 2014 for any city can be found at [5]-[6]. Intermediate values were determined by interpolation. Simulations were carried out assuming a load shedding of 2 hours (red bar in the figures), 4 hours (blue bar), 6 hours (green bar), and 8 hours (purple bar). The energy cost was calculated for each hour for the entire day based on the stated assumptions. The desired temperature range inside the house was set between 23^0C and 27^0C, and the desired humidity range was set between 50% and 70%. Rainy days and their effects are not visible from these graphs, because of the averaging process.

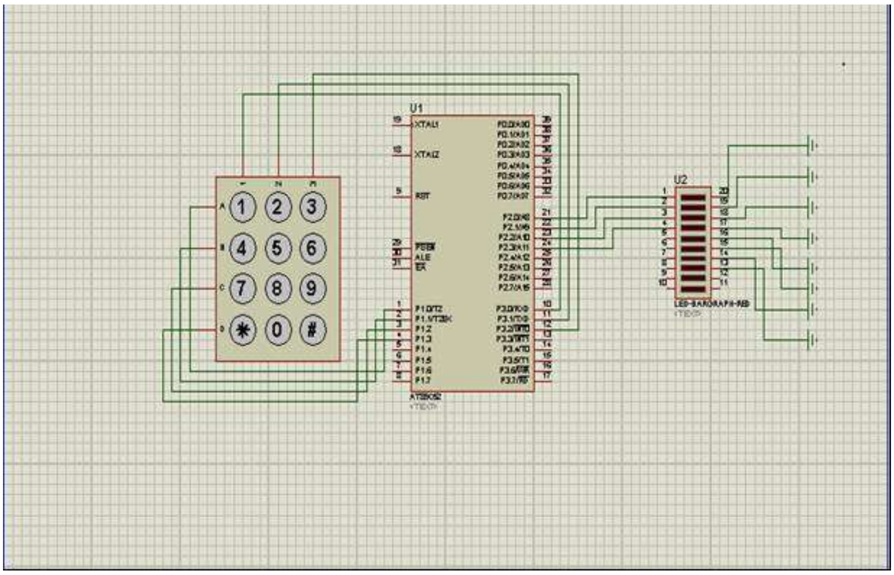

Fig. 7: Optional keypad connection for the ECM

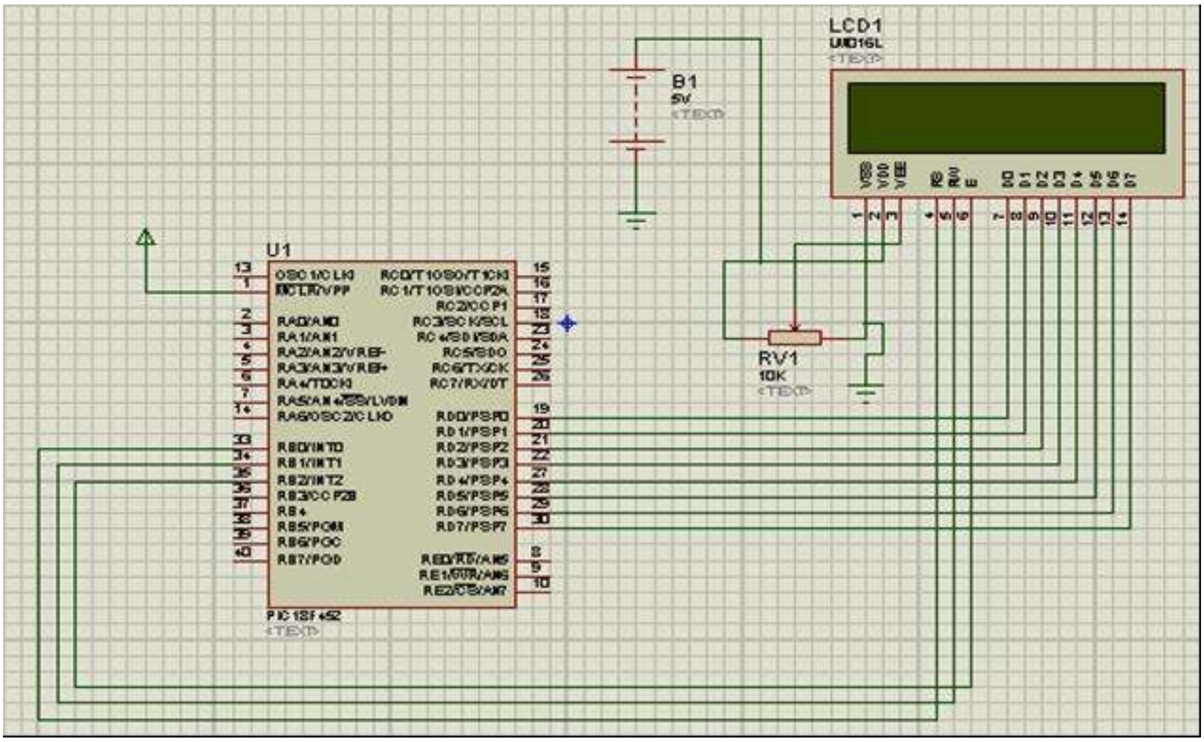

Fig. 8: Optional LCD connection for the ECM

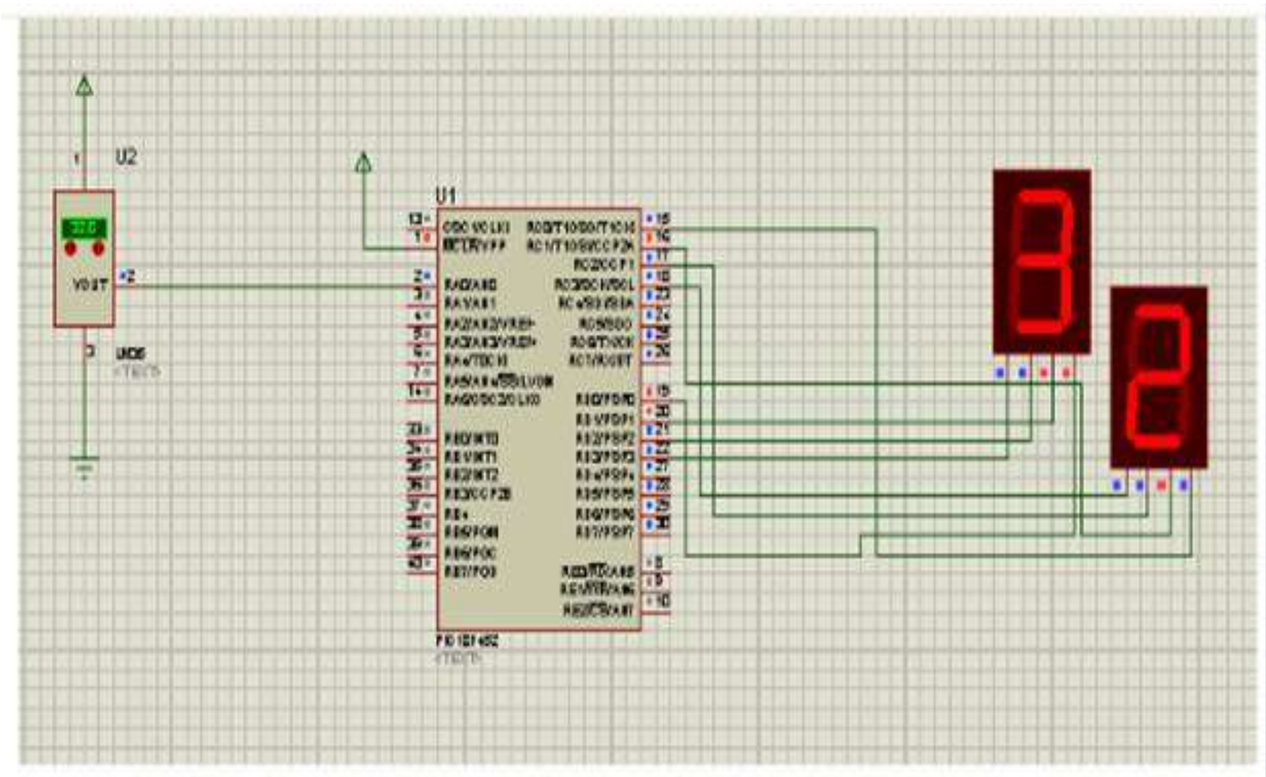

Fig. 9: Optional hex display connection for the ECM

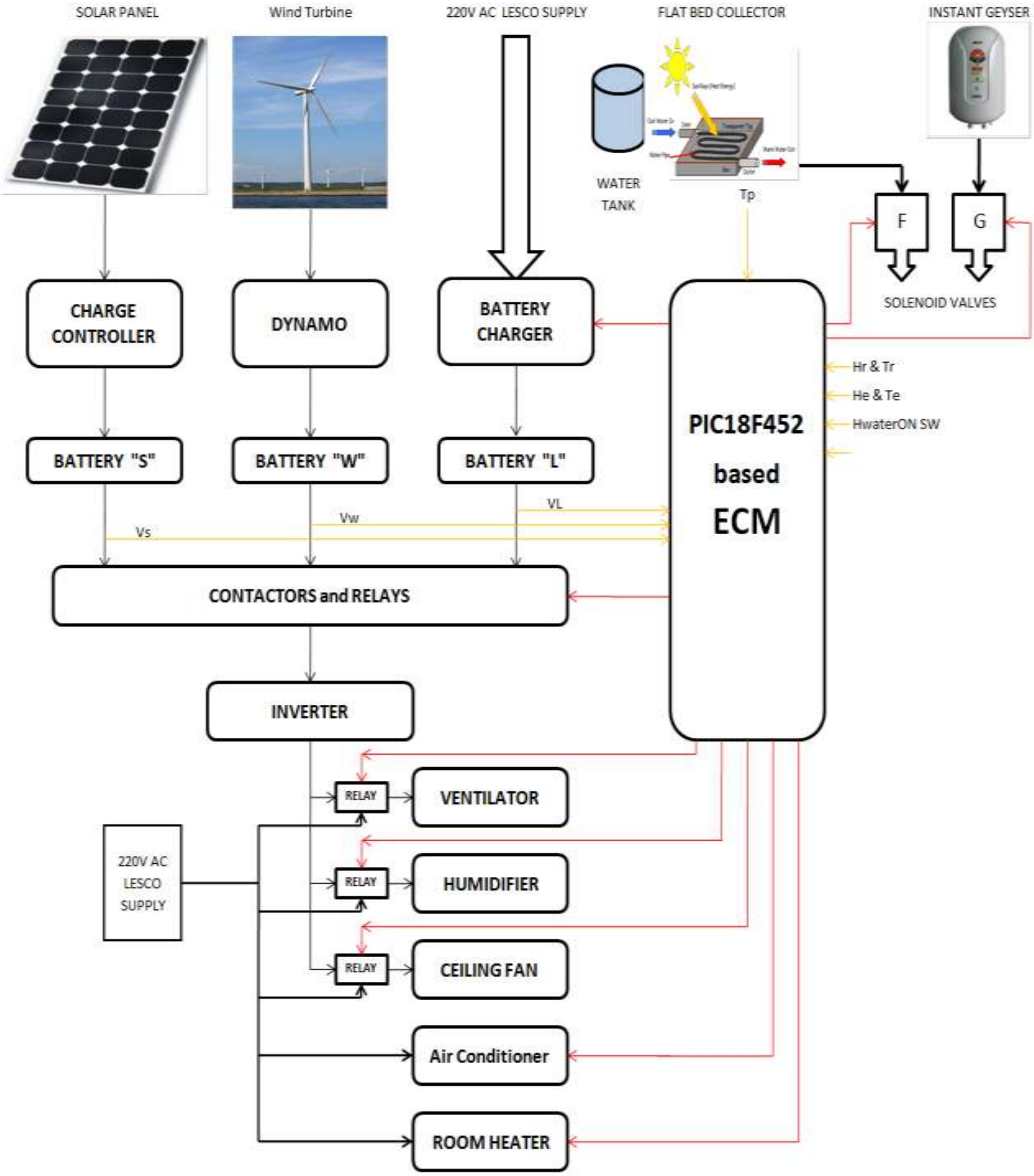

Fig. 4: Block diagram of the various components of the model house

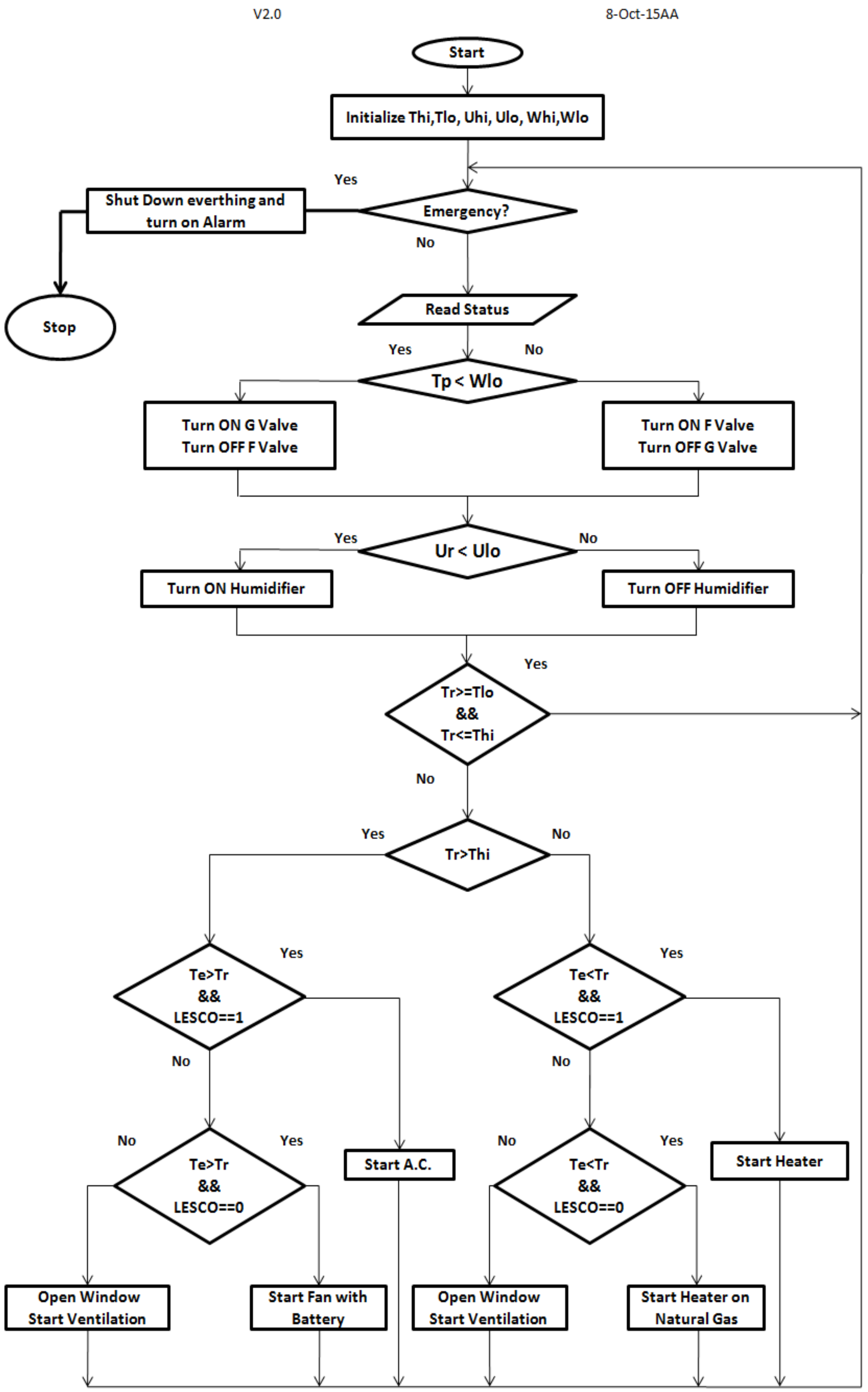

Fig. 5: Flowchart showing the operation of the embedded control module

```
// 15-Oct-15
Start
{
// Initialization phase: get min. & max. humidity and temp.  for the room and hot water temp.  from the user
Enter  Tlo, Thi,  Ulo, Uhi,  Wlo, Whi,
}
While(Start_Button==1)
{
If (Emergency==1) {Start_Button=0, Alarm=1} // Shutdown everything, and turn ON Alarm
Read the status of all sensors
If  (Ur<Ulo)
        Turn ON Humidifier
Else
        Turn OFF Humidifier

If  (Tp>Wlo)  //check if temperature of water in FBC is greater than min temp for the water
        Turn ON F valve, Turn OFF G valve
Else
        {
        Turn OFF F valve, Turn ON G valve
        }
If (Tr>=Tlo&&Tr<=Thi) //check if temperature of room is between max. and min. temperature of the room
        NOP
Else if (Tr>Thi)
        {
        If (Te>Tr &&LESCO==1) //check if environment temp. is greater than room temp with LESCO
        available
                Start A.C. , Stop fan and ventilator
        Else if  (Te>Tr&&LESCO==0) //check if environment temp. is greater than room temp with LESCO
        absent
                Start Room fan with Battery
        Else
                {
                Open window
                Start ventilation
                }
        }
Else
        {
        If (Te<Tr&&LESCO==1)//check if environment temp. is lesser than room temp with LESCO available
                Start   HEATER on LESCO
        Elseif (Te<Tr &&LESCO==0) //check if environment temp. is lesser than room temp with LESCO
        absent
                Start   HEATER on natural gas
        Else
                {
                Open window
                Start ventilation
                }
        }
}
```

Fig. 6: Control Algorithm for the Embedded Control Module (ECM)

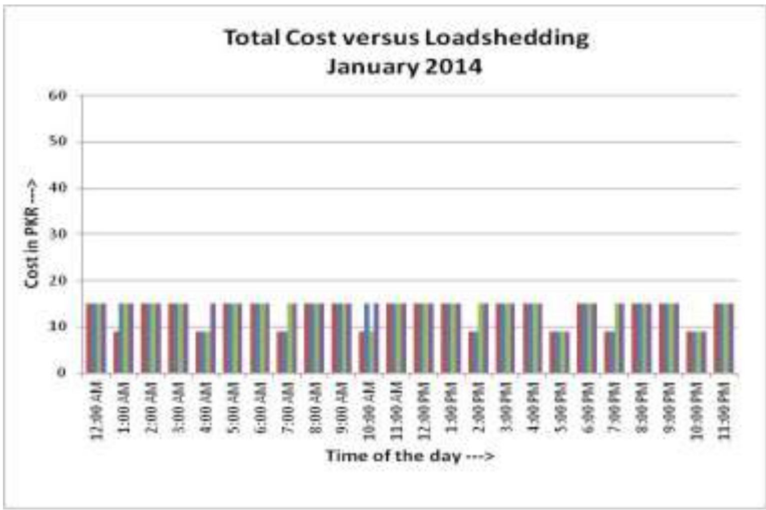

Fig. 10: Total cost versus load shedding for January 2014

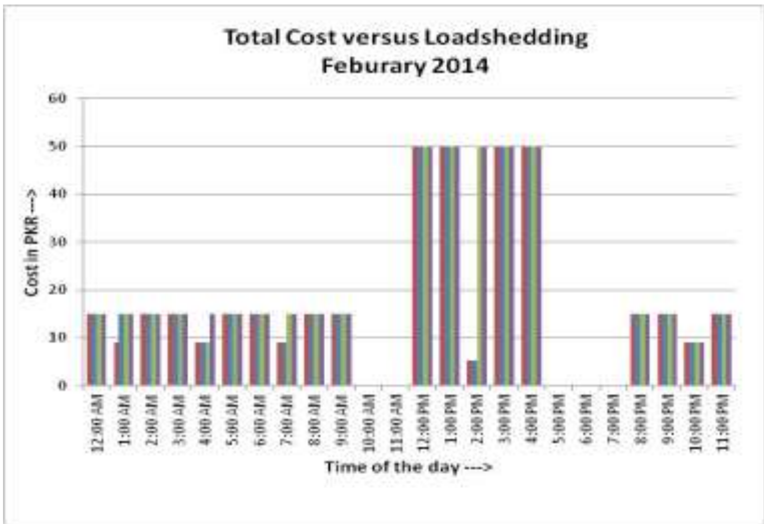

Fig. 11: Total cost versus load shedding for February 2014

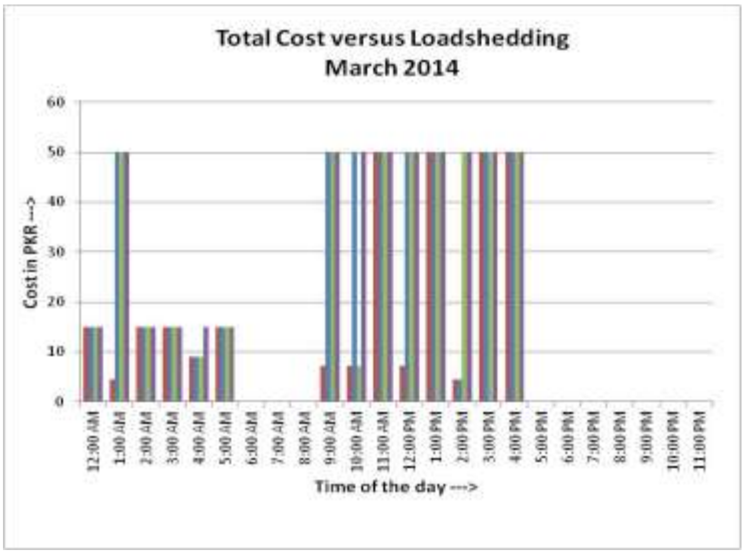

Fig. 12: Total cost versus load shedding for March 2014

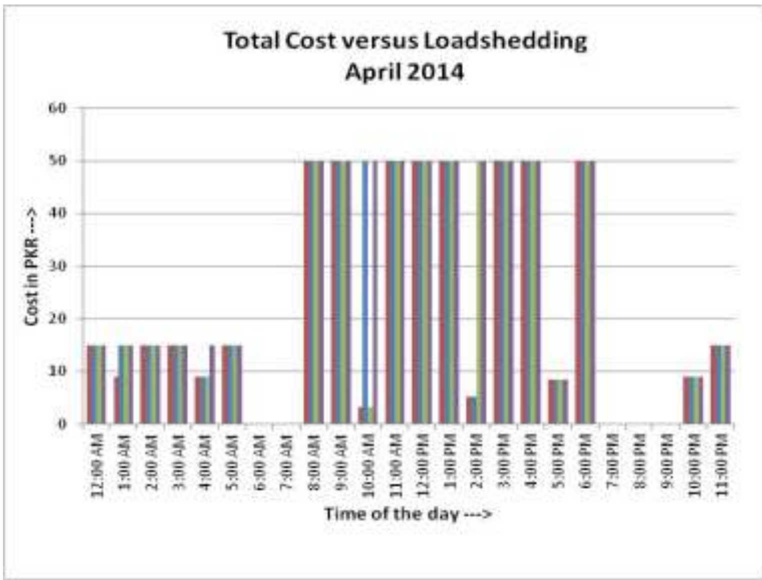

Fig. 13: Total cost versus load shedding for April 2014

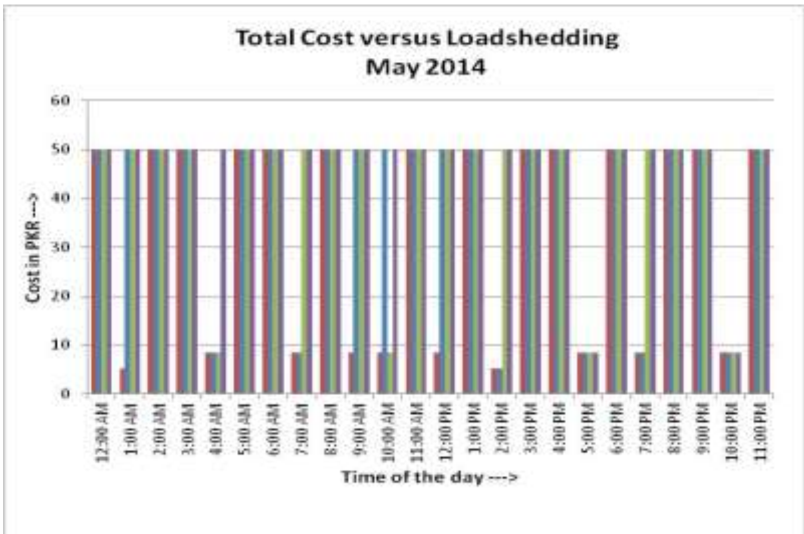

Fig. 14: Total cost versus load shedding for May 2014

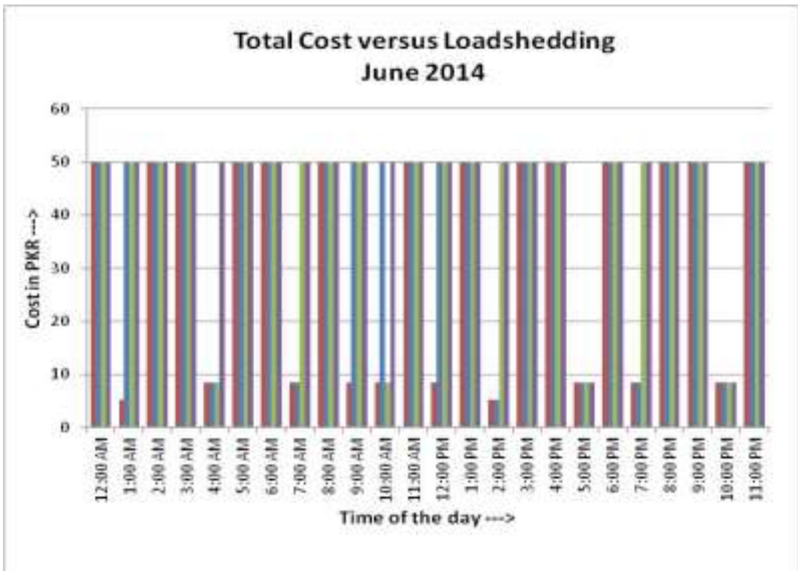

Fig. 15: Total cost versus load shedding for June 2014

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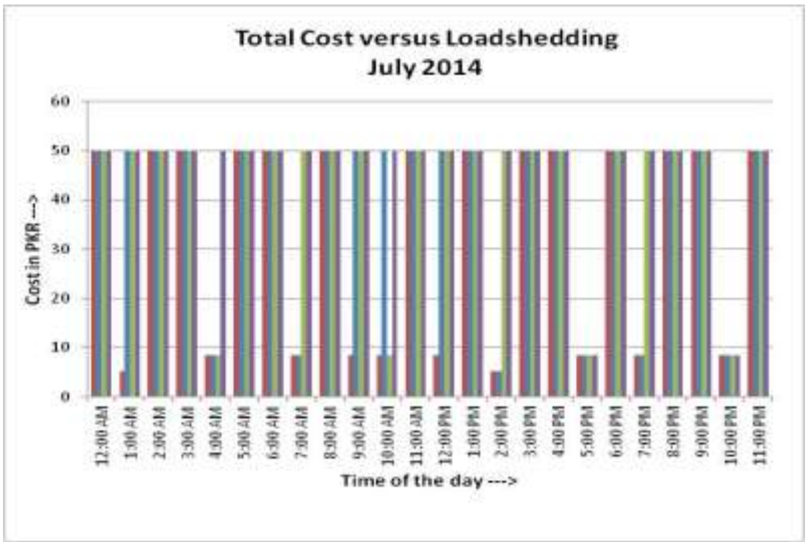

Fig. 16: Total cost versus load shedding for July 2014

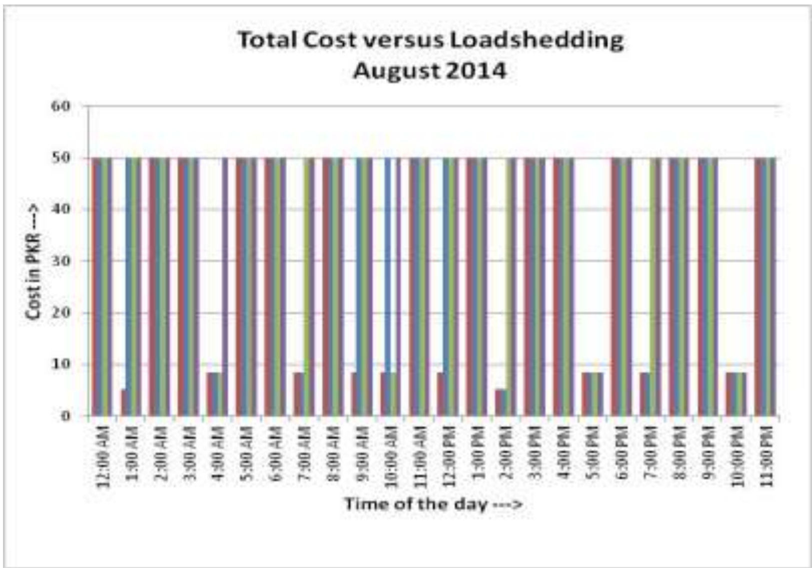

Fig. 17: Total cost versus load shedding for August 2014

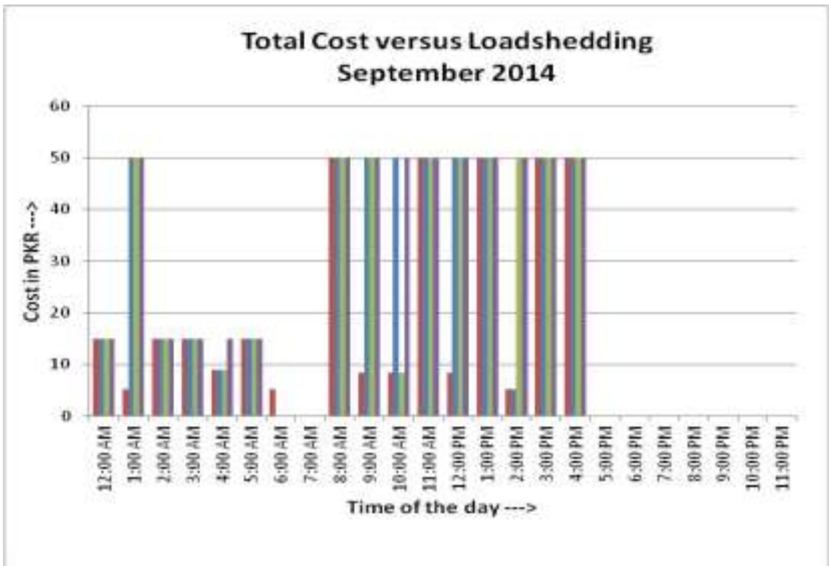

Fig. 18: Total cost versus load shedding for September 2014

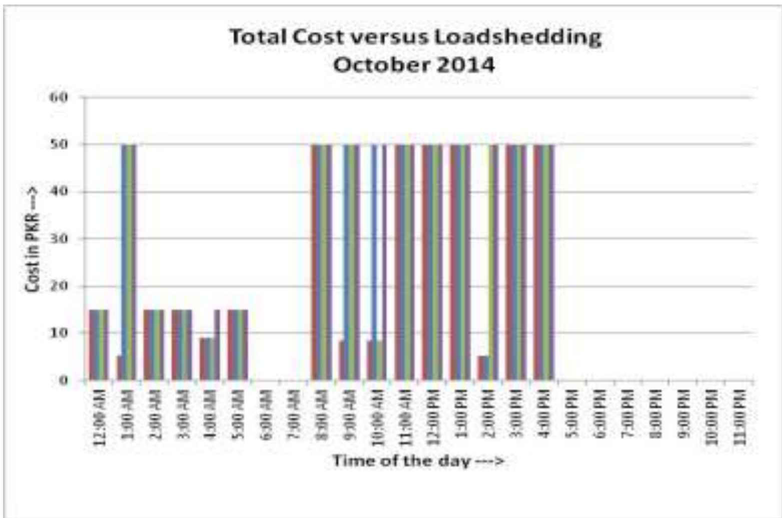

Fig. 19: Total cost versus load shedding for October 2014

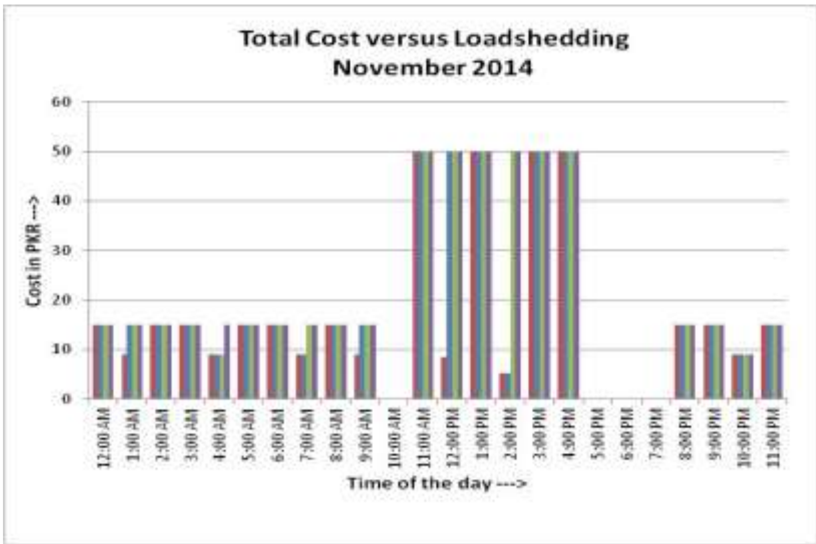

Fig. 20: Total cost versus load shedding for Nov. 2014

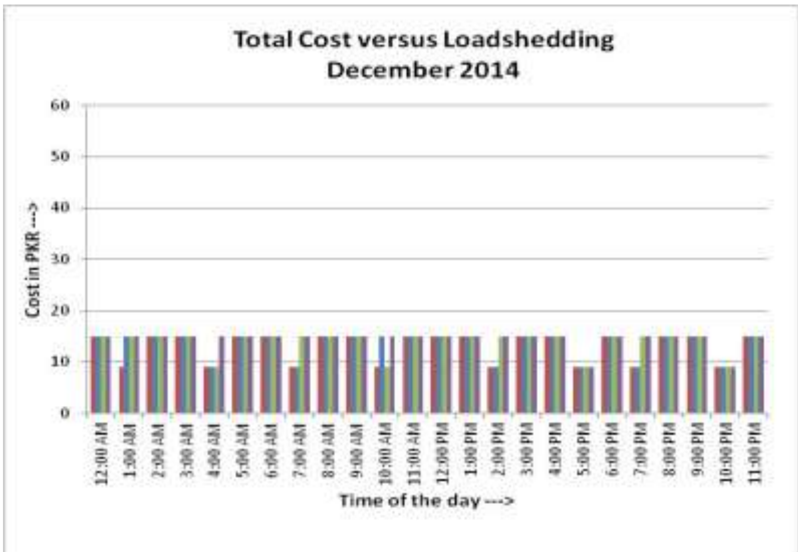

Fig. 21: Total cost versus load shedding for December 2014

CONCLUSIONS

The effects of variation of load shedding hours on the cost of energy consumed in a model house have been presented in this paper. The model house was designed as part of the C.A.S.E. project. Environmental data for Lahore, Pakistan, for all the months of year 2014 was used in the analysis. Results from MATLAB simulations have been reported.

It is clear from the data that since May to August are the hottest months in Lahore, the cost of the energy is the highest, and becomes more during load shedding hours. During February to April, and September to November afternoons are warm and nights are cool. Hence the cost during afternoon hours is the highest, and lowest during the morning and evening hours. The months of December and January have low energy consumption. Even though the temperature is lower than that required, it will result in the heater being switched on. This is because the cost of natural gas is assumed to be much less than the cost of other sources of energy.

The cost of energy is zero for certain hours during some months. This is because of the fact that the weather conditions are such that the temperature and the humidity inside the house are within the desired range, and the fact that the cost of lights is not included in the calculations.

A similar analysis can be performed for varying other parameters and studying their effect on the cost of energy consumed. As an example, cost can be calculated versus availability of sunlight at different hours of the day for different months. The analysis can be extended to other cities as well. By changing the specifications of the different sources of energy, and/ or the loads, the effect on the total cost can be observed for larger buildings.

Among the many benefits of this study are that it will help in avoiding wastage of energy. The results will also be helpful to design engineers for the selection of the most appropriate energy system for a particular situation.

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