Development of Energy Saving Smart Home Prototype

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Abstract

In this work, we are interested in developing a prototype of smart home for energy saving. The prototype uses a microcontroller PIC18F458 with various sensors such as a temperature sensor, infrared sensor as well as actuators to control the lights, air conditions, as well as the fans appropriately etc. It detects the number of people in a room, adjusts a proper temperature for the air condition, turns on the fan if needed, turns on and off the light appropriately. The simple measurement shows that using the sample prototype can save the electricity cost for every test case.

Keywords: *Smart home, Energy saving, Fuzzy temperature controller, PIC18F458*

1. Introduction

Nowadays, an energy saving is crucial for every home. We use electricity in our daily life such the use of lights, air conditions, fans, oven etc. From researches, cooling and lighting as well as heating can comprise of 60% of the energy consumed of each household [4]. As we use more energy, we consume more electricity; we need to spend more expense on it.

In this work, we are interested in developing an energy saving home using an intelligence technique. We employ the embedded microcontroller in our prototype and have a program to control the usage of electric appliances in the house. Though it is not a novel idea in overall, it is a good start to show the employment of a embedded system with the intelligent technique for building a smart home is not too complicate to be realistic. In fact, it can inexpensively be built while many existing commercial software is costly. Also, with the prototype, it is quite easy to show the cost saving using the proposed prototype.

There are many existing works that present the smart home idea. The work in [1] presents in the aspect of the building construction to audience as consultants, system integrators, and electric installers. It shows to integrate electric appliances in the buildings using KNX-bus and network. The article presents benefits of the controls intelligently. The work in [6] focuses in the energy consumptions of washers. It compares the brands of washes and the electricity used including water saving.

In another level, the work in [3] proposed the energy minimization in the view of instruction set design. The experiment was based on FPGA soft core implementation.

There are many interests in designing circuits that optimizes the power/energy consumption as well as the power/energy estimation. For example, Lee, Nam and Chang were interested in the model to estimate the energy by cycles based on FPGA platforms [7]. Lewis, Ghosh, and Tzeng also presented the energy estimation in a high level, i.e., the server system [8]. Cambre, Boemo, and Todorovich present the lowenergy arithmetic operations implemented in NIOS II [5]. At a user level, in [9], the way to estimate the power usage of an electric household device is presented.

FPGAs can be used to create a rapid prototype as it can be implemented as a soft processor [17]. It can be used to control the electric household appliances, for example, Alizem Motor-Control IP with the Cyclone III FPGA from Altera® [12]. Another example is the integration of Altera, Echelon, and Altia's integrated energy aware solution. The control from FPGA is connected to the appliances. The Altia provides HMI message center which connects to the users and the utility company [13].

2. Backgrounds

For a device, there are major power components [2]. Standby power is the power used if the appliance is in the standby mode. Dynamic power is the main power used when running the device. It is from the switching activities (charging and discharging). I/O power is the external switching for the input/output devices connected by pins.

Normally, standby power depends on the hardware, especially die-junctions in the board. Thus the junction temperature should be minimum to save the standby power. Figure 1 shows the relationship of the standby power and the junction temperature.

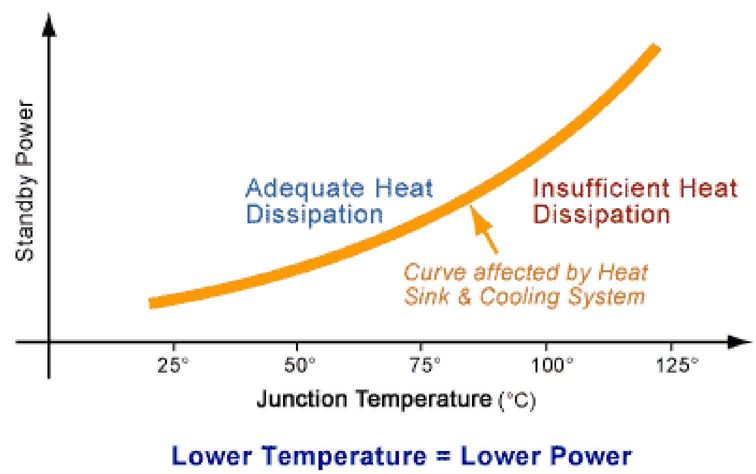

Figure 1. Relationship of Junction Temperature and Standby Power [2]

For dynamic power, it is important to use for charging and discharging the internal capacitances in the circuit. It includes the power used for logic elements and routing. All logic elements need to be considered such as RAM, adders/multipliers, transceivers etc.

At last, for I/O power, it considers the charging and discharging of external load capacitors attached to the device output pins, output driver circuits, and external termination networks.

The electricity consumes in each house may vary depending the number of appliances used, the type of appliances, the standby power. Since the model to calculate the expense depends on countries, the total cost of each household varies. In [4], the calculation example is shown for the USA case study.

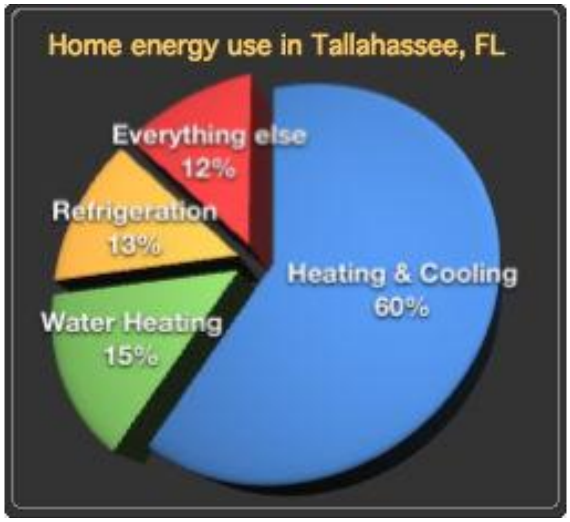

Figure 2. Chart of the Average Expense of Electricity [4]

Figure 2 shows the example of energy consumed on average in a home in 2007[4]. We can see that the major portion is the heating and cooling device. The literature presents some interesting information such as the watts consumed for each type of devices such as heating, cooling, household appliances, computers and televisions etc. It also presents the way to save the cost of electricity. The important points are using the space heater and turning it on only when there are people in the room, using the ceiling fan instead of the air condition, turn off the lights when nobody in the room [4]. It is clear that the automatic control of these appliances will help saving the expense.

PIC (Peripheral Interface Controller) is a microcontroller which attempts to include every peripherals such as program memory, RAM, EEPROM, serial port, I2C, PWM, A/D etc. It has a CPU and program/data memory. It has a small board and a minimal extra add-ons. It is appropriate for small simple tasks, not very computation-intensive ones. PIC has many families such as 16xxx, 17xxx, 18xxx etc.

PIC18F458 [10,11] contains 77 instructions, 33 I/O pins, 1-2 timers, watch dog, 12 UARTs, SPI, PWM, CAN, 8-bit A/D. It can interface with external program memory of size 32K x 16. The flash program memory makes it flexible to program and make changes. It supports In Circuit Debugging (ICD). Figure 3 shows the attributes of PIC18F458. Figure 4 shows input/output pins of it and Figure 5 is the architecture.

Device	Program Memory		Data Memory		I/O	10-bit A/D (ch)	Comparators	CCP/ ECCP (PWM)	MSSP		USART	Timers 8/16-bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)					SPI™	Master I²C™		
PIC18F458	32K	16384	1536	256	33	8	2	1/1	Y	Y	Y	1/3

Figure 3. The Attributes of PIC18F458

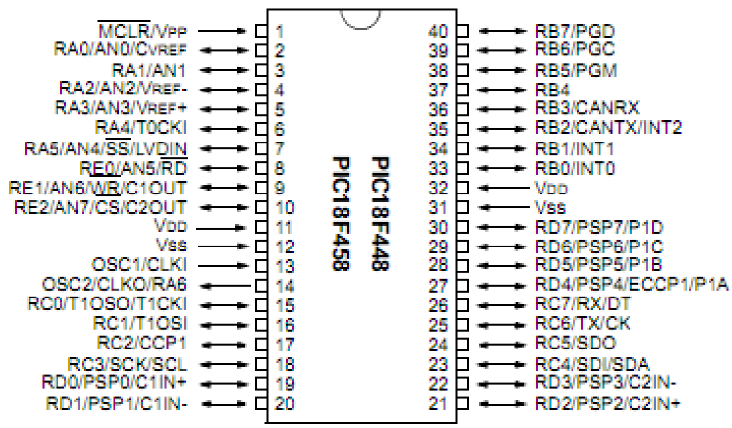

Figure 4. The Pin Diagrams of PIC18F458

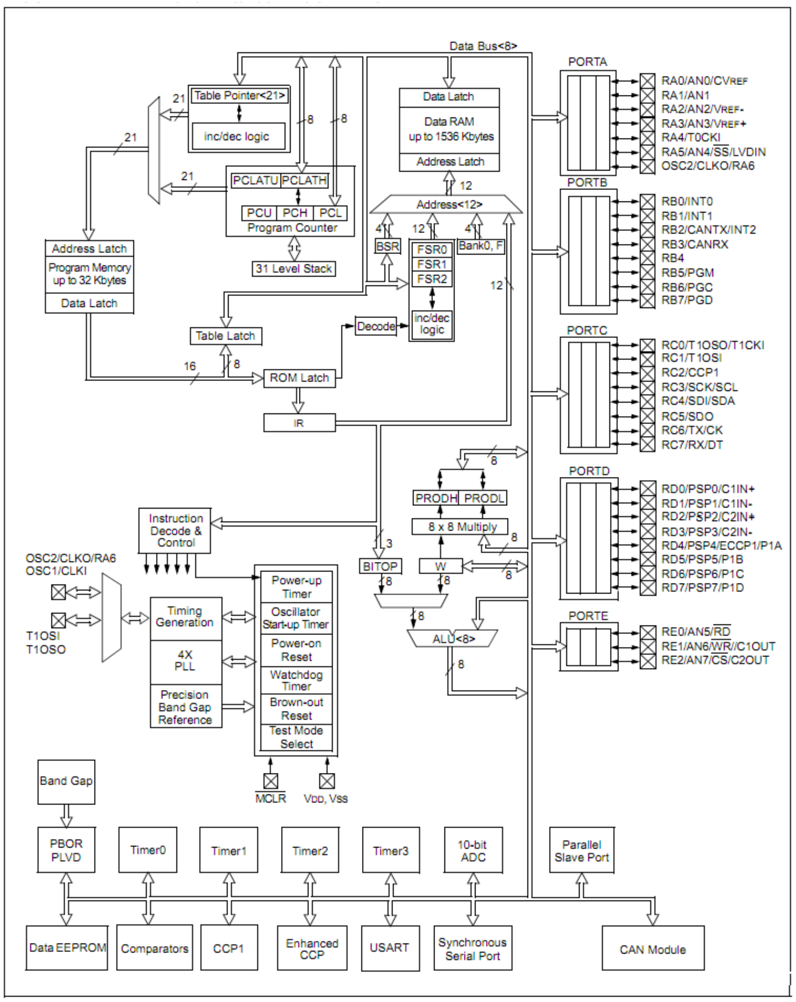

Figure 5. The Architecture of PIC18F458

We use the ETT board namely ETT-CP-PIC V3.0 (ICD2). It includes power source (5 voltage regulators), reset circuit, clock, download port, serial port, one channel of RS 232, ETT CON 34PIN (ET BUS I/O 34PIN) and some extra space for I/O customization. The board is shown in Figure 6. The board architecture is shown in Figure 7.

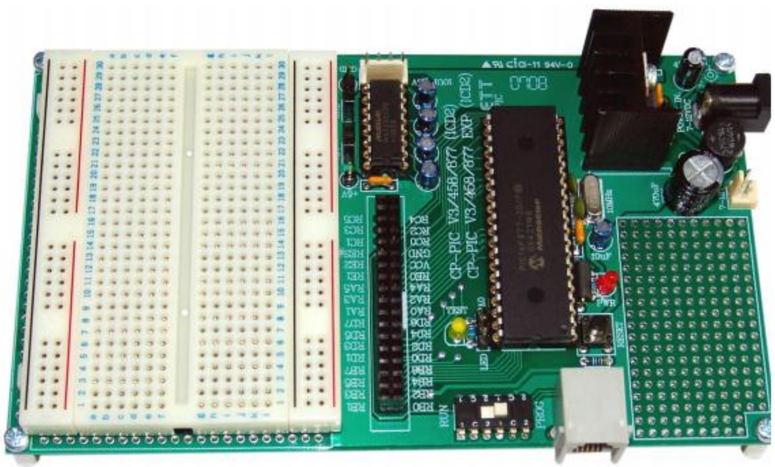

Figure 6. PIC18F458 from ETT (CP-PIC V 3.0EXPANSION(ICD(2.

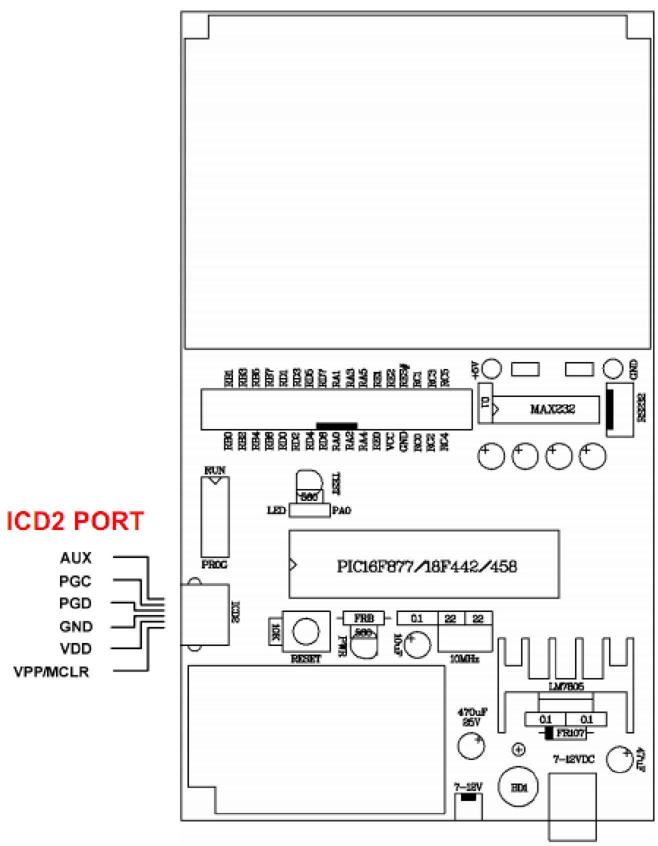

Figure 7. Architecture of PIC18F458 from ETT (CP-PIC V 3.0EXPANSION(ICD(2.

We use thermistors [18] to measure the temperature. It is made from a semi-conductor which is sensitive directly to the change of temperature. It has a resistant between 100-450,000 Ohm-cms. This is displayed in Figure 8.

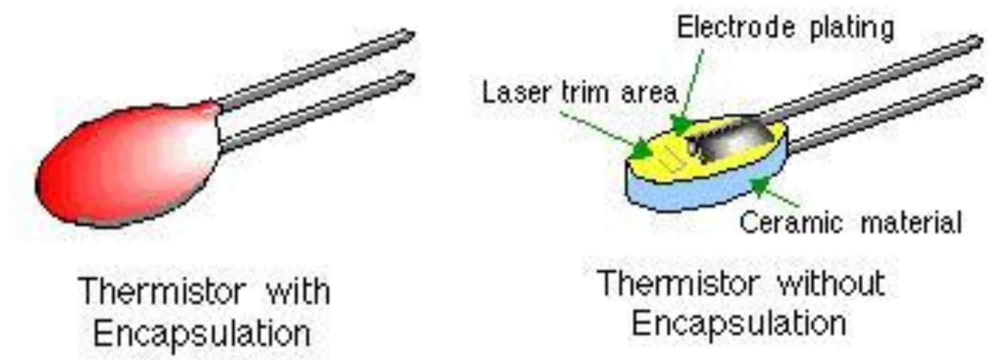

Figure 8. Thermistor and its Components

To calculate the electric usage bill [19], currently we use the following formula: Baseline + FT + Service + VAT. The calculation is divided into two categories. First for a residential house, the rate is shown in Table 1 and Table 2.

Table 1. Normal Rate for the Usage is not Greater than 150 Units per Month

Units		Energy cost (Baht/unit)	Service (Baht/month)
First 15 units	(from 0 – 15)	1.8632	8.19
The next 10 units	(from 16 – 25)	2.5026	8.19
The next 10 units	(from 26 – 35)	2.7549	8.19
The next 65 units	(from 36 - 100)	3.1381	8.19
The next 50 units	(from 101 – 150)	3.2315	8.19
The next 250 units	(from 151 – 400)	3.7362	8.19
More than 400 units	(from 401 (	3.936	8.19

Table 2. The Rate for the Usage that is Greater than 150 Units per Month

Units		Energy cost (Baht/unit)	Service (Baht/month)
First 150 units	(from 0 – 150)	2.7628	38.22
The next 250 units	(from 250 – 400)	3.7362	38.22
More than 400 units	(from 401 and more(	3.936	38.22

The usage of one unit is calculated from using the electric appliance 1,000 Watt for 1 hour. In particular,

1 unit = the power (Watt) of the electric appliance x the number of electric appliance / 1,000 x total hours used per day.

For example, if we have 5 types of electric appliance: 10 light bulbs of the 46 Watts used for 6 hours per day. Then it will consume 46 x 10/1,000 x 6 =2.76 units or 30 x 2.76=82.8 units for a month.

For an electric cooker (600 Watts), we use it for 30 minutes per day. It will consume 600 x 1 / 1,000 x 0.5 = 0.3 units or) 30 x 0.3) = 9 units per month.

For a 125-Watt refrigerator, we use for 24 hours. Suppose the compressor works about 8 hours and then it consumes 125 x 1 / 1000 x 8 = 1 unit or) 30 x 1) = 30 units per month.

For a 2,000-Watt air condition (20,000 BTU), it is used for 12 hours per day. Suppose the compressor works about 6 hours and then it consumes 2000 x 1 / 1000 x 6 = 12 unit or) 30 x 12) = 360 units per month.

The above calculation is just an approximate in overall. For different brands of each appliance type, it consumes different units. Also, for the air condition, it also depends on the temperature setting as well.

To calculate the electric bill, suppose we use 494 units as above, and we use Table 2 as a reference. The first 150 units costs)150 x 1.8047 Baht = (270.71 Baht. The next 250 units costs)250 x 2.7781 Baht = (694.53 Baht. The remainder of 400 units costs) 494-400 = 94 units x 2.9780 Baht = (279.93 Baht. With the service charge of 40.90 Baht, totally it is 1,286.07 Baht.

For the FT (Energy Adjustment Charge), it is fixed monthly by the Metropolitan Electric Authority. The FT value is multiplied with the units used. If the FT for May, 1992 is 24.44 Baht per unit, then Ft 494 x 24.44 = 120.73 Baht. Totally,)1,286.07 + 120.73) = 1,406.80 Baht. With 7% VAT, it becomes 1,505.25 Baht.

To calculate the temperature from sensor, we use the following equation.

$$V_{cc} = I(R_1 + R_T), \quad V_0 = \left(\frac{Vcc}{R_1 + R_T}\right) R_T, \quad R_T = \frac{\text{Vout R1}}{\text{Vcc - Vout}} \quad R_T = R_0 e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

$$T(K) = \frac{B}{\ln\left(\frac{R_T}{r_\alpha}\right)}$$

$$r_\infty = R_0 e^{\frac{-B}{T_0}}$$

Where: T_0 = T $_{0}$ = 298.15 K for room temperature
R_1 = 10 kΩ , v_{cc} = 5v
B = 4050 K Thermister No. 103 , R_0= $10 \times 10^3 \Omega$. For T_0= 298.15 K, at room temperature R_1 = 10 kΩ , v_{cc} = 5v , B= 4050 K Thermister no.103, R_0= $10 \times 10^3 \Omega$.

If Vout is 2.54

$$r_\infty = 10 \times 10^3 e^{\frac{-4050}{29815}} = 0.01261$$

$$R_T = \frac{2.54 \times 10 \times 10^3}{5 - 2.54} = 10325.203 \quad = 10325.203$$

Then,

$$T(K) = \frac{4050}{\ln\left(\frac{10325.203}{0.01261}\right)} = \frac{4050}{13.615} = 297.47(K)$$

Then, we change it to centigrades.

$$^\circ C = {}^\circ K - 273$$

$$^\circ C = 297.47 - 273$$

$$^\circ C = 24.47\ {}^\circ C$$

3. Hardware and Software Prototype Design

We use the infrared sensors to detect the people entering a room. The sensors are shown in Figures 9-10. Figure 9 is an infrared sensor. Figure 10 shows the temperature sensor. Figure 11 is an interconnection to PIC. Figures 12-15 are details connections from PIC to outputs and inputs.

Then we create a database storing information about electric appliance in each room, usage for each electric appliance, FT, electric calculation formula

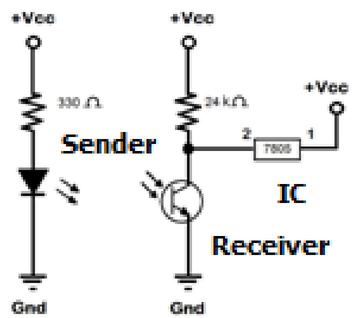

Figure 9. Infrared Sensors

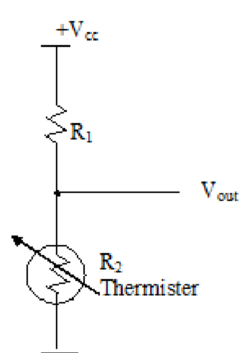

Figure 10. Temperature Sensor

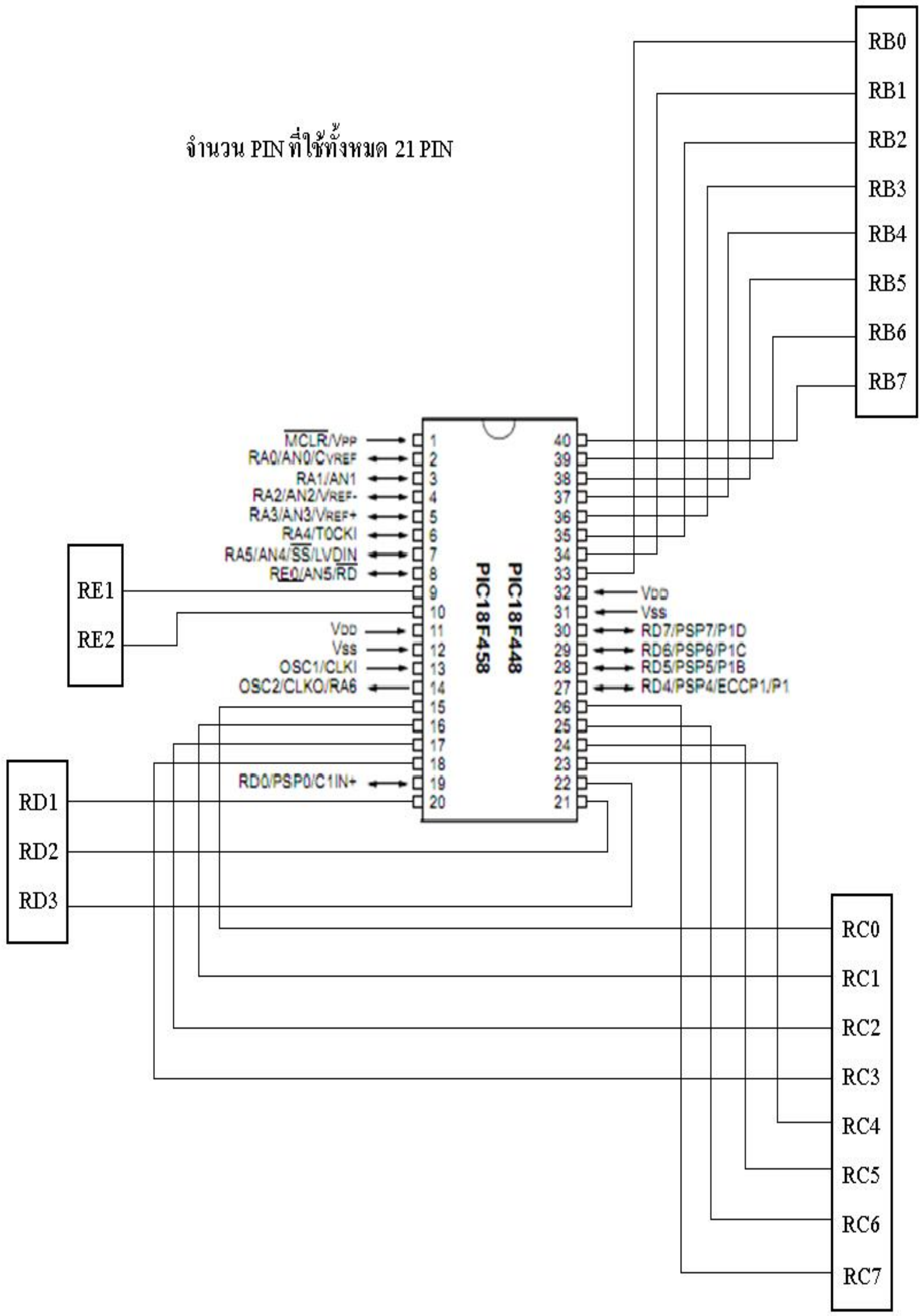

Figure 11. The Whole Connection to PIC

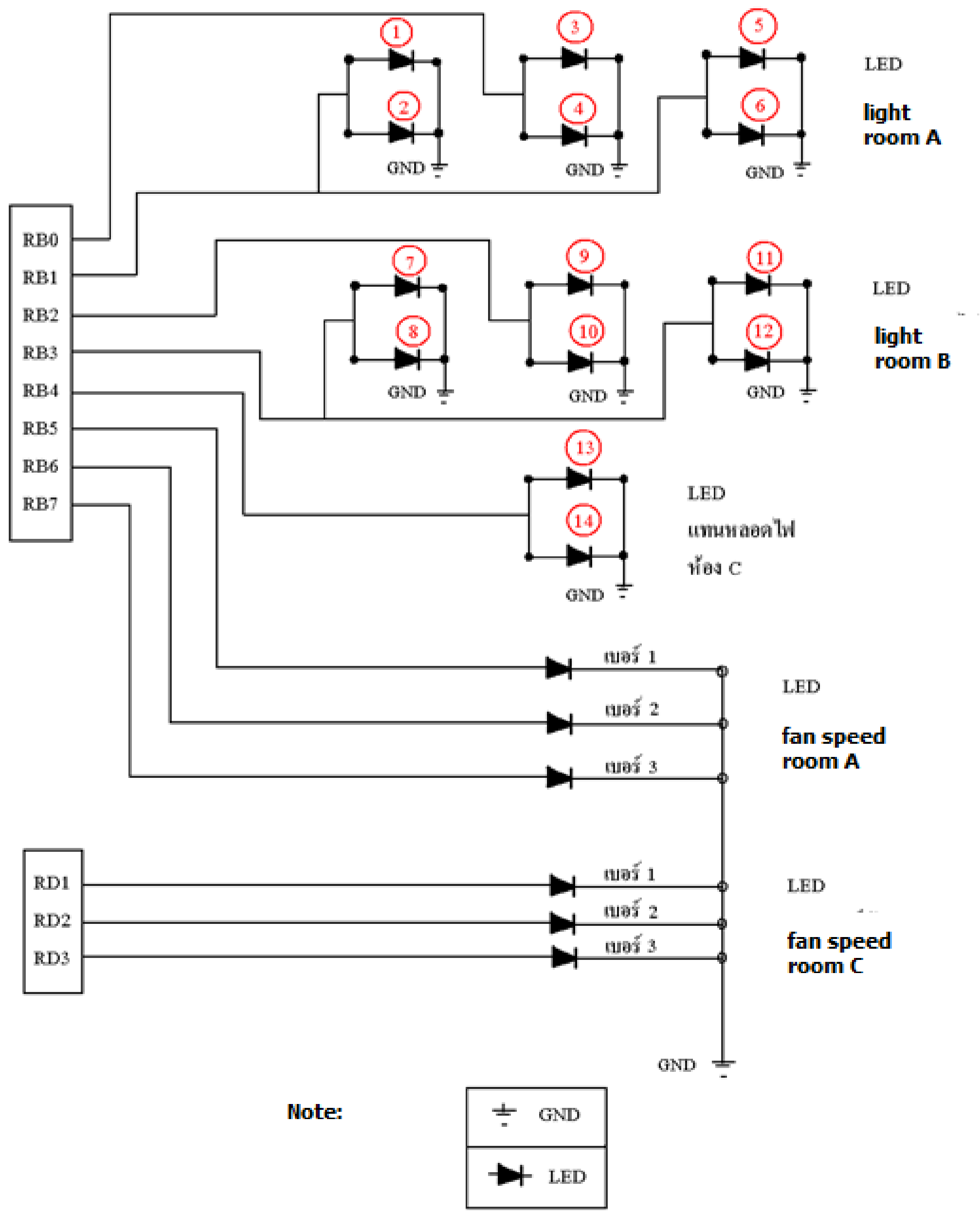

Figure 12. Output Connection of PIN RB0-RB7 and PIN RD1-RD3

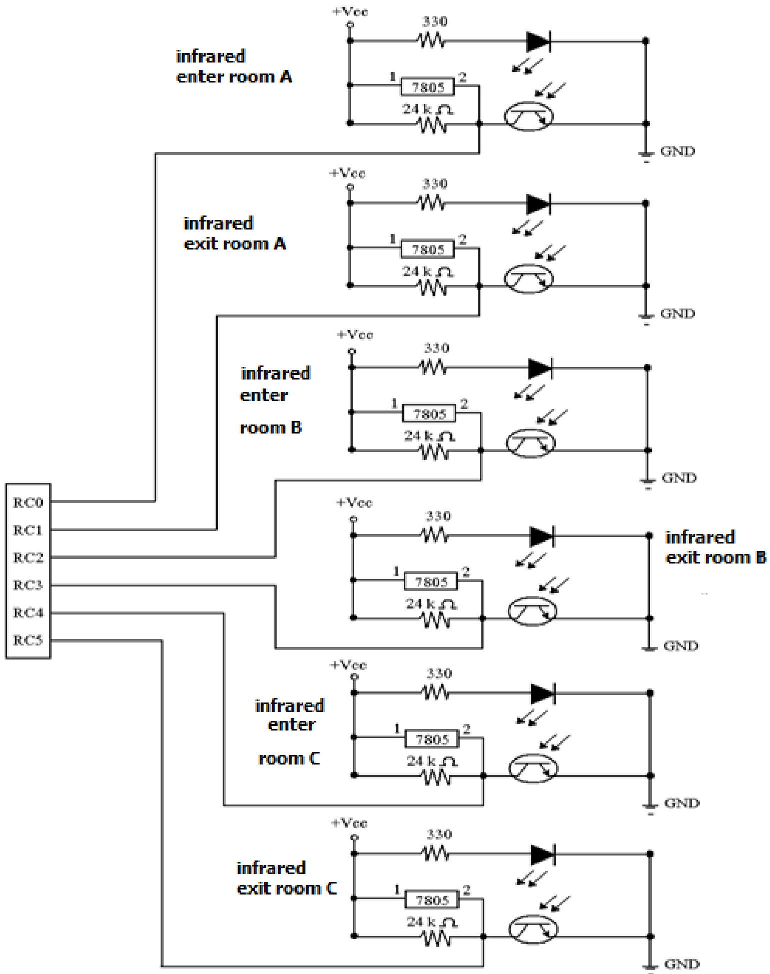

Figure 13. Input Connection to RC0-RC5

Figure 12 is the interconnection to fan speed output and lights of each room. Figure 13 is the interconnection to the infrared to detect persons each room. Figure 14 is the input connection to the temperature sensor for each room. Finally, Figure 15 is the connection to the computer to control by our software.

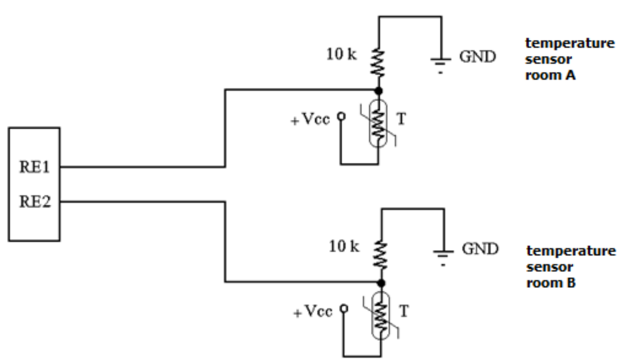

Figure 14. Input Connection of PIN RE1-RE2

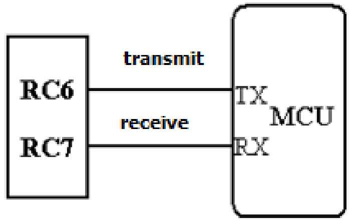

Figure 15. Connection of PIN RC6-RC7 to the Computer

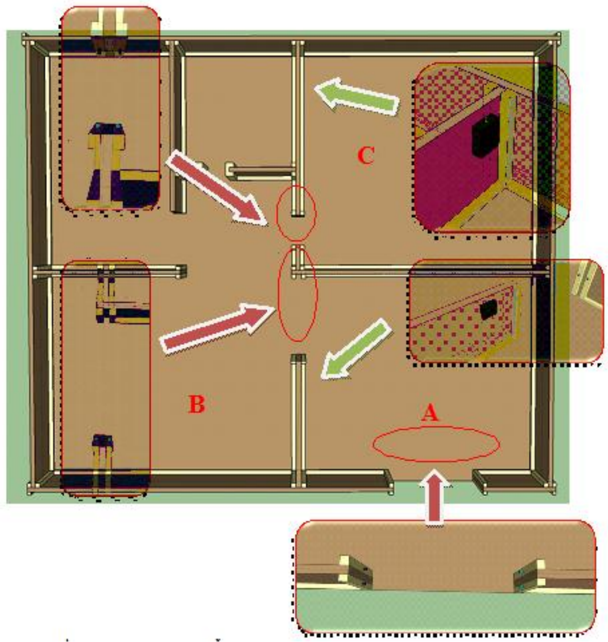

Figure 16. Layout of the Room and Sensor Locations

We have 5 tables stored in the database keeping the electric usage formula, as well as the information about each electric appliance (watts consumed) and the appliance usage log each day.

Figure 16 shows the layout of each room A, B and C as well as infrared sensor locations at the entrance of each room (pointed by the arrows). The zoomed boxes indicate where the sensors are installed at each door.

Figure 17 shows the layout of the light locations in each room as well as temperature sensor locations. Assume that we install 2 lights in room C, 6 lights in room A and 6 lights in room B respectively. The rules in this setup for turning the lights are to turn the middle ones first. When the number of people is less than 2, we turned the middle ones. Then, when the number of people is more we gradually turn on the left one and the light one accordingly. This rule can actually be changed to make it suitable for the light locations, size of the rooms and the number of people considered.

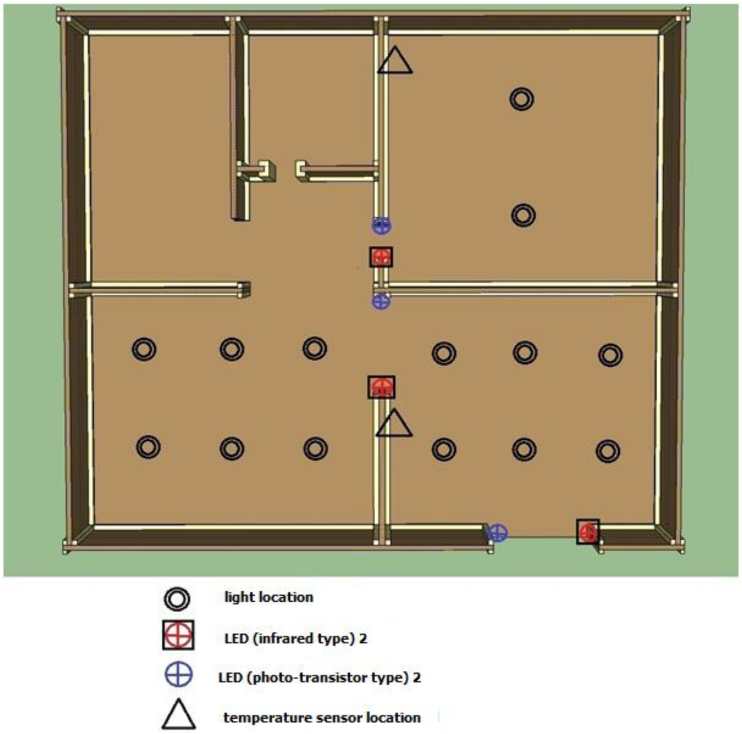

Figure 17. Layout of the Room, Lights and Temperature Sensor Locations

Figure 18. Infrared Sensor Testing

Figure 18 shows the testing scenarios for people entering and exiting a room. Figure 17 shows the LED connection the model indicating the light positions in each room. Each LED corresponds directly to the position mentioned in Figure 15. In Figure 18, we show the LED setup for each fan. Each fan consists of three speeds. The LED light corresponds to each speed of the fan.

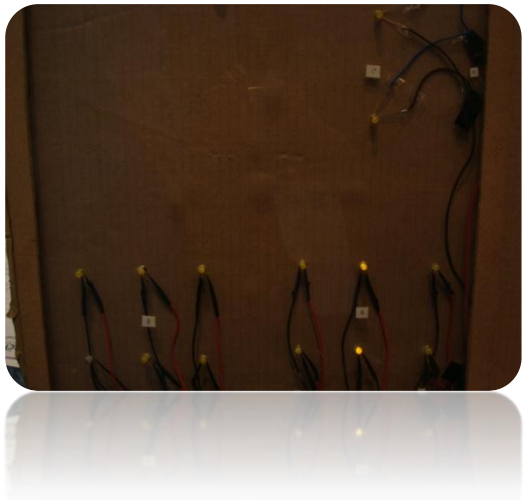

Figure 19. LED Representing Lights Turned On

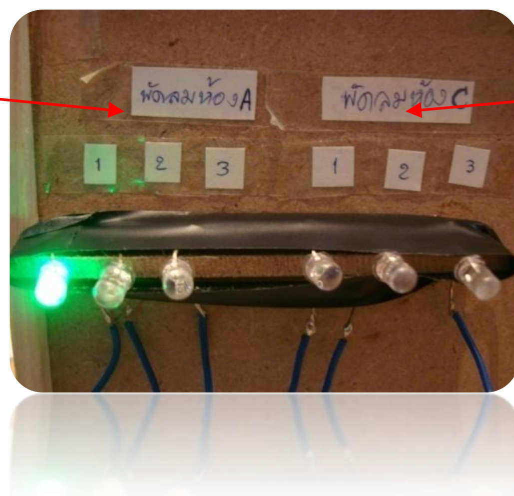

Figure 20. LED Representing Fan Speed Selection

Finally, Figure 21 present the user interface for the software showing the status of the number of people in each room, lights, fans and costs.

At 1), the total number of people is shown. At 2), we show the number of people in each room. At 3), the light switch status for each room is shown. At 4), the temperatures for each room are displayed. Point 5) shows the fan speed selection for each room that the fans are installed. Point 6) is the total watts for all appliances and total watts used. At last, point 7 is the total costs by this setting in baht and the saving compared with turns all on for 8 hours a day. Point 8 presents the total time the system is monitored and point 9 is the list of the appliances in all the rooms (listed from the database).

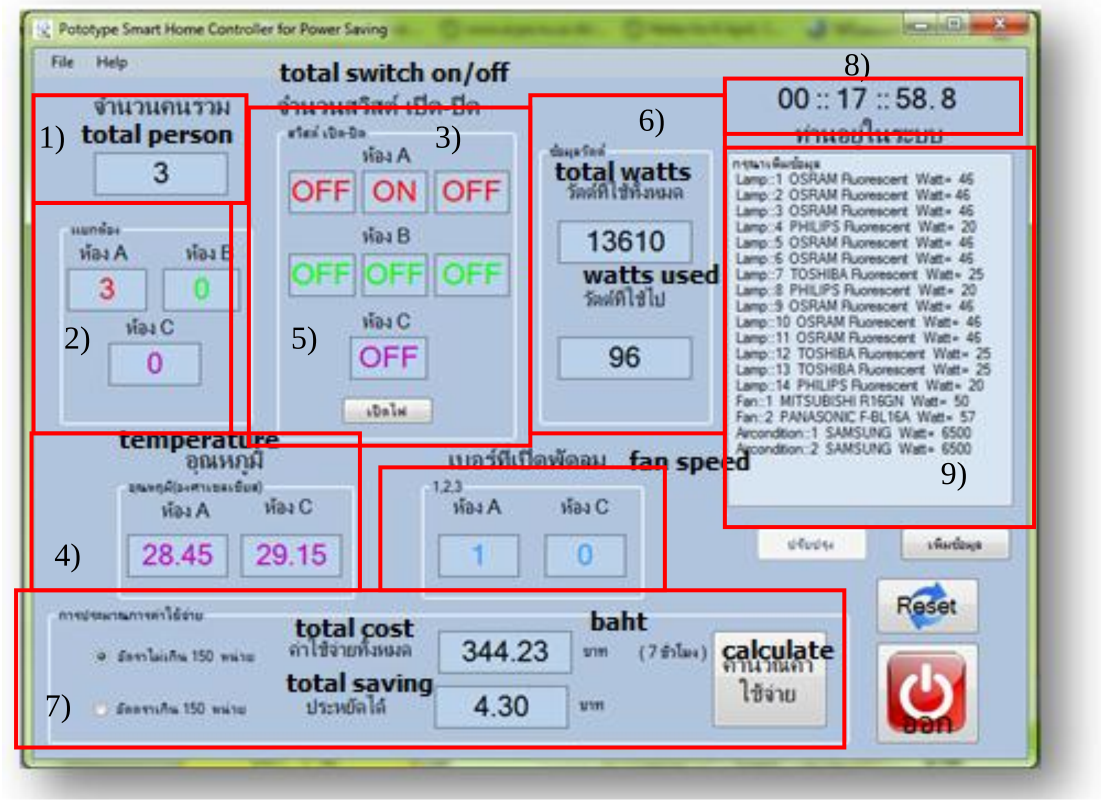

Figure 21. Software Interface

4. Some Experimental and Results

We compare the usage of the electric appliances with our control and the baseline usage where the electric appliances are used for 8 hours a day.

Table 3 lists the sample electric appliances considered in this experiment. Column ‘type’ is the type of the appliances, column ‘Desc’ is the description of each one such as the brand name and model, column ‘watt’ is the watts consumed for each one. This information is stored in the database.

Table 4 shows the sample results for various testing. The first columns are the number of persons totally. Columns “Person per room” is the number of persons per room. Column “light switch Room A” is the status of the switch in room A and similarly for room B and room C in the next columns.

Table 5 is the status of the fan speed using the tested fan controller. The first column ‘temp’ shows the current temperature. The second column ‘#per’ is the number of persons in the room. The next column ‘Fan Speed no’ is the fan speed setting after using the fuzzy controller [14.15]. The last column ‘Fan Speed No. (Aft. Rounding)’ shows the value after rounding to the closest integer to send the fan speed controller.

Table 3. Sample Electric Appliances

No.	Type	Desc	watt
1	Lamp	Panasonic AS1	40
2	Lamp	PHILIPS Fluorescent	20
3	Lamp	TOSHIBA Fluorescent	25
4	Lamp	OSRAM Fluorescent	30
5	Lamp	Panasonic AS1	40
6	Lamp	OSRAM Fluorescent	30
7	Lamp	PHILIPS Fluorescent	20
8	Lamp	OSRAM Fluorescent	30
9	Lamp	OSRAM Fluorescent	30
10	Lamp	PHILIPS Fluorescent	20
11	Lamp	TOSHIBA Fluorescent	25
12	Lamp	PHILIPS Fluorescent	20
13	Lamp	OSRAM Fluorescent	30
14	Lamp	TOSHIBA Fluorescent	25
15	Lamp	Panasonic AS1	40
1	Fan	MITSUBISHI R16GN	50
2	Fan	HATARI HA-T16D1	50
1	Air Condition	CENTRAL AIR	4000
2	Air Condition	DAIKIN	5400

Table 4. Sample Results for Various Cases

# per	Person per room			light switch Room A			light switch Room B			Light Switch RoomC
	A	B	C	1	2	3	1	2	3	1
1	1	0	0	OFF	ON	OFF	OFF	OFF	OFF	OFF
1	0	1	0	OFF	OFF	OFF	OFF	ON	OFF	OFF
1	0	0	1	OFF	OFF	OFF	OFF	OFF	OFF	ON
5	3	2	0	OFF	ON	OFF	OFF	ON	OFF	OFF
5	4	1	0	ON	OFF	ON	OFF	ON	OFF	OFF
8	3	3	2	OFF	ON	OFF	OFF	ON	OFF	ON
9	9	0	0	ON	ON	ON	OFF	OFF	OFF	OFF
11	1	9	1	OFF	ON	OFF	ON	ON	ON	ON
15	5	8	2	ON	OFF	ON	ON	ON	ON	ON

Table 5. Results for Temperature Control Testing

temp)°C(	# per	Fan Speed no.	Fan Speed No. (Aft. Rounding)
28.45	1	1.14	1
29.44	3	1.24	1
30.00	5	1.3	1
25.00	7	1.4	1
36.00	1	1	1
33.33	3	1.63	2
33.33	5	1.63	2
35.60	4	1.86	2
29.55	10	2.25	2
34.66	6	1.96	2
34.33	10	2.73	3
32.77	12	2.57	3
35.00	9	2.71	3
30.00	13	2.6	3
27.00	14	2.8	3
32.44	15	3	3

In Table 6, Column '#per' presents the number of total people in the scenario. Column 'person per room' is the number of person per each room. Column 'room A light switch' is the status of each light switch for each test case. Column 'Fan and air condition' presents the status of the fan and the air condition in each room. The total watts used are shown in column 'total watts used' and the total cost each case is shown in Column 'total cost'.

Note in Figure 17 that we layout the light numbers from left to right each column contains two lights. When there are one or two people in the room we turn on the middle ones (3,4) first. See the first three rows for the case of one people. For the case of 5 peoples (case 3,2 and 4,1 accordingly), if for the case (4,1) (row #5), considering room A where there are 4 people, we turn on the light number 1,2,5,6 which are the left and right ones and turn off the middle ones 3,4.

As a whole, we can see that using the prototype can save the electricity cost for every case. This demonstration shows that the smart home can be built easily with simple software and controllers from scratch and how we can earn the energy saving by introducing such automation.

Table 6. Results for Various Tests

	# per	person per room			room A light switch			room B light switch			room C light switch	fan and air condition		on time (mins)	total watts used	total watts saved	total cost (Baht)	total saving (Baht)
		A	B	C	1 (หลอดที่ 1,2)	2 (หลอดที่ 3,4)	3 (หลอดที่ 5,6)	1 (หลอดที่ 7,8)	2 (หลอดที่ 9,10)	3 (หลอดที่ 11,12)	1 (หลอดที่ 13,14)	1 (เครื่องที่ 1)	2 (เครื่องที่ 2)					
1.	1	1	0	0	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF	15	4105	5820	4.361	2.925
2.	1	0	1	0	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	30	50	9875	9.263	9.217
3.	1	0	0	1	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF	ON	25	5505	4420	7.719	3.726
4.	5	3	2	0	OFF	ON	OFF	OFF	ON	OFF	OFF	ON	OFF	10	4155	6220	3.087	1.934
5.	5	4	1	0	ON	OFF	ON	OFF	ON	OFF	OFF	ON	OFF	50	4230	6145	15.490	9.560
6.	8	3	3	2	OFF	ON	OFF	OFF	ON	OFF	ON	ON	ON	70	9660	1156	21.616	2.517
7.	9	9	0	0	ON	ON	ON	OFF	OFF	OFF	OFF	ON	OFF	40	4235	6140	12.351	7.640
8.	11	1	9	1	OFF	ON	OFF	ON	ON	ON	ON	ON	ON	20	9755	1070	6.174	0.665
9.	15	5	8	2	ON	OFF	ON	ON	ON	ON	ON	ON	ON	40	9870	955	12.351	1.186
	total													300			92.412	39.37

6. Conclusion

Energy saving is an important issue nowadays. This paper presents the building of the simple smart home prototype using a PIC microcontroller. The model is created for the room floor plans. The temperature sensors are put in the rooms and infrared sensors are put at the door. The LED setup shows the output of the fan speed controls and light switch. The database of the electric appliances are created. The software shows the status of the people in the rooms and temperatures. The microcontroller program determines the lights to switch on/off and the fan speed setting. Finally, the total watts used can be estimated and the user knows the electricity cost in real-time. The prototype with the simple automation can save the energy cost in all most cases.

Acknowledgements

This work was supported in part by Thailand National Software Contest sponsored by NECTEC.

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