Managing Energy demand in Smart Houses Using Sensors and Logic Circuits

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***Abstract* — There is an ever increasing demand on consumption of electrical energy but the production of energy is limited. A growing need to design smart houses that would reduce consumption of electrical energy is emerging. In this paper we propose a simple electrical design based on logic circuits and sensors. The paper also addresses one of the main concerns of third world countries in which a country needs to encourage dependence on local designs and products and reduce importing goods using foreign currency. The sensors detect daytime and presence of people inside houses. Based on these two pieces of information, we can make our houses tailored to put light on and off just to serve the needs of the users without any losses. The electrical design is very simple and saves almost 15% of the consumed energy.**

***Keywords* — Energy Demand, Energy Management, Sensors, Smart Houses.**

I. Introduction

One's own house should serve the needs and hopes of its residents and only then it can be called home [1]. Towards this aim, smartness can serve a lot to make houses feel like homes by automatically controlling the appliances and devices existing in a house [1]. The notion of Smart houses can become widely accepted in every society based on how good the technology can make houses which are beneficial to their users [2]. A study was performed in reference [2] to know the categories in which smart homes can serve the needs of the society best. Behavior of people throughout the day is investigated to know the ways where saving energy using technology can happen [2], [3].

The study discussed by Kim el al. is user-centered to draw a full picture of the issues that affect houses related to how to design, install, and use technology [2]. Smart houses must serve best their users and at the same time serve as a building block to smart cities. Apanaviciene*et al*. discusses the characteristics which must exist in a smart house to serve in building smart cities [4]. The most important thing to make houses smart is to use devices and equipment which are enabled by smart cities and vice versa so that buildings and environment interact coherently [4].

Making smart houses revolves around the idea of making them more comfortable and user friendly. At the same time, they must save energy to help in decreasing global warming and lessening the pollution to the environment. The proposed system by Chasta *et al*. controls the lighting (on/off & dimming control), air conditioning equipment and safety devices such as fire alarms and gas alarms in a building [5]. The manufacturing society is increasingly introducing devices which are connected either in wired and/or wirelessly modes to help users improve their energy consumption management [6]. Those devices use minimal amount of energy so as to help in decreasing global warming and environmental pollution [6]. The following projects are listed as examples of the efforts done to construct smart buildings.

Gong *et al*. proposed a smart house design based on the Zigbee technology [7]. All aspects of the design are discussed including software and hardware implementations. The design is described to be reliable [7] but the Zigbee technology is considered to be expensive relative to other technologies as discussed in reference [8].

Shyr *et al*. proposed a smart system to control the lighting on a university campus [9]. Detailed breakdowns of the network, application, control, equipment, and perception layers are discussed as shown in reference [9]. The proposed system proves to be successfully working and helps in saving electrical energy [9].

The energy sector is closely linked and integrated to the construction sector through applying Internet computer related solutions for energy management of houses and cities [10]. Devices and equipment are designed and customized exclusively for pre-defined smart applications to ease the job of the designers with their smart buildings. Marinakis *et al*. introduces advanced Internet of Things (IoT) based systems for reducing energy consumption in buildings [10].

The authors Davies *et al*. [11] and Jabbar *et al* [12] proposed designs of smart houses based on the IOT technology. The authors use microcontrollers, sensors, wireless technologies and relays to build the proposed smart systems. In addition, the system in [12] is accessed via laptops or smart phones. In both references, low cost reliable smart systems are reported and recommended to users [11], [12].

Reference [13] discusses the huge increase on demand on electrical energy accompanied by an increase in global warming. Smart Home Energy Management System (SHEMS) has been proposed as a way to help reduce the consumed energy in houses. Three states of users' activity in a house are detected namely active, away and sleep modes [3]. Based on them a smart system is designed based on WiFi technology and GSM technology. The proposed system saved 18% of energy consumption as reported by the authors [13].

Modern engineering systems which include high technological equipment in addition to saving energy make houses more appealing to buyers generally [14] and in Moscow specifically [14]. The author in reference [14] discusses how design of houses can be altered to make their prices more affordable to people with middle income. The

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ideas discussed may affect the design of house complexes in the years to come [14]. Here, a design of a House Energy Management System (HEMS) to reduce consumption of energy is discussed. We want to design a smart HEMS that takes into consideration two issues. First, the existence of humans inside rooms can be detected and used to save electricity used in lighting. Second, the different times during the day in which different lighting intensity is needed can be detected and used to save energy. Based on these two issues, we define conditions that must be met to minimize the consumption of energy inside houses.

The paper addresses one of the main concerns of third world countries in which a country needs to encourage dependence on local designs and products and reduce importing goods using foreign currency. We propose designing smart houses to decrease power consumption using very simple circuits of logic gates which doesn't need any programming or complicated designs. It goes along the same line of plug and play products. The rest of the paper is organized as follows. The designs of intelligent HEMS for a house composed of one room and then for a house composed of two rooms are discussed in section two. In section three, the designs are programmed using Simulink in Matlab to simulate results and compare them with expected ones. In section four, the calculations for the consumption of energy in the different categories of a typical house are shown. A comparison between the amounts of energy saved when using the proposed HEMS and another system proposed by a different author is demonstrated in section five. Finally, conclusions and future work are discussed in section six.

II. Design of Logic Circuits

In this section, we discuss the steps to design a digital electronic system to optimize the consumed energy in a house. We start with a design that is suitable for a house composed of one room. Then, we expand the design to be suitable for a house composed of two rooms.

A. *One Room Design*

For a one room design, the system is designed for a house composed of one room only as shown in Fig. 1.

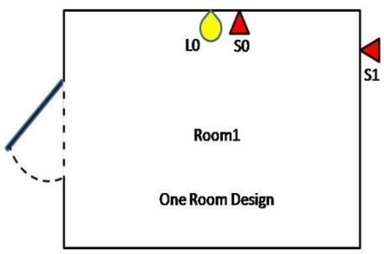

Fig. 1. A sketch showing the design of a house composed of one room (room 1) with S_0, S_1 sensors and L_0 Lamp.

The one room house which is shown in Fig. 1 has two inputs (S_0 & S_1) and one output (L_0). The definition of all used symbols can be found in Table I.

TABLE I: Definition of All Inputs and Outputs of a One Room Design

Symbol	Definition
S_0	Sensor to detect human existence in room 1.
S_1	Sensor to detect Sunlight time.
$L_0(t)$	Present state (on/off) of lamp in room 1.
$L_0(t+1)$	Next state (on/off) of lamp in room 1.
L_{i0}	Intermediate output to put lamp on/off permanently.
T_0	Intermediate output to put lamp on/off for limited time.

We want to design a system based on logic circuits to control the lighting of room 1 according to the following conditions:

If a person exists in room 1 during sunlight time, the lamp inside the room give lighting with half power.

If a person exists in room 1 during nighttime, the lamp inside the room give lighting with full power.

If a person exists in room 1 and then leaves it, the lamp inside the room give lighting for a limited time and then goes off.

If a person exists in room 1 and remains in it, the lamp inside the room is put on permanently.

The different values of the sensors S_0, S_1 and the output $L_0(t)$ are listed in Table II which is composed of 7 columns. The truth table listing all different possibilities is shown. There are three inputs among which two regular inputs namely S_0 and S_1. As long as $S_1 = 1$, the time is sunlight time and energy delivered to put on the lamp is half that delivered during nighttime. The third input is the state $L_0(t)$ which represents the present state of the lamp in the room whether it is on or off. For the three inputs, there are 8 possibilities representing all possible combinations for them as shown in Table II. There are two intermediate outputs namely L_{i0}, T_0 and one next state $L_0(t+1)$. L_{i0} represents the signal to activate lighting of the lamp permanently in case a person exists in the room. While T_0 represents the signal to activate the lighting of the lamp for a limited time in case a person leaves the room.

TABLE II: State Truth Table for a One Room Design

	Pres. (t)	Input		Interm. Output		Next(t+1)
#	L0	S0	S1	Li0	T0	L0
0	0	0	0	0	0	0
1	0	0	1	0	0	0
2	0	1	0	1	0	1
3	0	1	1	1	0	1
4	1	0	0	0	1	1
5	1	0	1	0	1	1
6	1	1	0	1	0	1
7	1	1	1	1	0	1

The possibilities in Table II can be summarized in four scenarios. First, if we have $L_0(t) = 0$ and $S_0 = 0$, then this means that the present state of the lamp is off and there is no person in the room respectively. The response will be that we have $L_{i0} = 0$ and $T_0 = 0$ which means that the next state of the lamp is off. Second, if we have $L_0(t) = 0$ and $S_0 = 1$, then this means that the present state of the lamp is off and there is a person in the room respectively. The response will be that we have $L_{i0}=1$ and $T_0=0$ which means that the next state of the lamp is on permanently. Third, if we have $L_0(t)=1$ and $S_0=0$, then this means that the present state of the lamp is on and there is no person in the room respectively. The response will be that we have $L_{i0}=0$ and $T_0=1$ which means that the next state of the lamp is on for a limited time. Fourth, if we have $L_0(t)=1$ and $S_0=1$, then this means that the present state of the lamp is on and there is a person in the room respectively. The response will be that we have $L_{i0}=1$ and $T_0=0$ which means that the next state of the lamp is on permanently. From Table II, the above scenarios are valid if we have $S_0=0$ which stands for being during night time. Also, the above scenarios are replicated when we have $S_0=1$ which stands for being during sunlight time. The only difference is that during sunlight time the power delivered to the lamp is half that delivered to the lamp during night time. Above, we discuss the problem of when to put a lamp on or off and for how long. The issue of delivering full energy or half energy to a lamp is discussed later.

The possibilities listed in Table II are summarized in the Mealy state machine as shown in Fig. 2. Each state, whether present or next, is presented by a circle. Each arrow is directed from present state $L_0(t)$ to next state $L_0(t+1)$ and the corresponding inputs (S_0 S_1) are written on the arrow.

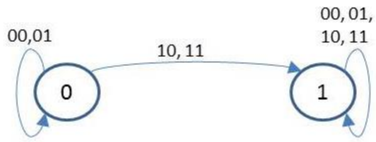

Fig. 2. Mealy state machine for a one room design.

From Fig. 2, we can see that there is no arrow that goes directly from present state one to next state zero because the lamp inside the room never goes off immediately even if no one is in the room. The light stays on for some time and then goes off as predefined in the conditions of the design.

Next, two 3-variable Karnaugh maps are used to obtain the equations for the two intermediate outputs L_{i0} and T_0 as shown in Table IIIa and b, respectively.

TABLE III: 3-VARIABLE KARNAUGH MAPS FOR A ONE ROOM DESIGN (A) L_{i0} (B) T_0 .

(a-Li0)

			S0	
	0	0	1	1
L0	0	0	1	1
		S1		

(b-T0)

			S0	
	0	0	0	0
L0	1	1	0	0
		S1		

From Tables IIIa and b, the equations of the intermediate outputs L_{i0} and T_0 are as follows:

$$T_0(L_0,S_0,S_1)=\overline{S_1}\;\overline{S_0}L_0(t)+S_1\overline{S_0}L_0(t) \qquad (1)$$

$$L_{i0}(L_0,S_0,S_1)=\overline{S_1}S_0+S_1S_0 \qquad (2)$$

We can see from eq. (1) that it is composed of two identical terms if we exclude the parameter S_1. Eq. (1) is applicable if the lighting in room 1 is put on for a limited time. Same for eq. (2), it is composed of identical terms if we exclude the S_1 parameter. Eq. (2) is applicable if the lighting in room 1 is put on permanently. The S_1 parameter is responsible for detecting the sunlight time from the night time. In both equations, the first term include S_1 which is true for the night time duration and the second term include S_1 which is true for the sunlight time duration. We deduce from the design of the logic circuit for a one room that we don't need to include the S_1 parameter. The equations for the night and sunlight times are identical with the only difference of having $\overline{S_1}$ for the equations of the night time and S_1 for the equations of the sunlight time. This can be applicable to the two room design to simplify the equations by reducing the number of input variables by not including S_1.

The total output to the lamp of room 1 is given by the following next state equation:

$$L_0(t+1)(L_0,S_0,S_1)=L_{i0}+T_0 \qquad (3)$$

The $L_0(t+1)$ is composed of an OR gate which delivers energy to the lamp if any of the intermediate outputs is true. Next we expand the design to be suitable for a two room design.

B. Two Rooms Design

In this subsection, we apply the same steps explained in subsection II.A to obtain the state equations of the HEMS for the two rooms design. We don't use the S_1 parameter here as we now know that once the equations for the night time are obtained, we can deduce the equations for the sunlight time and vice versa. For a two room design, the system is designed for a house composed of two rooms as shown in Fig. 3.

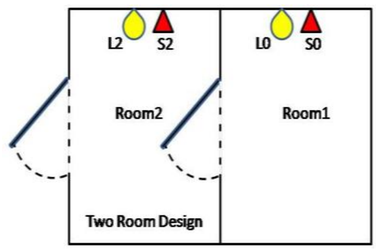

Fig. 3. A sketch showing the design of a house composed of two rooms (room 1 and room 2) with S_0 , S_2 sensors and L_0 , L_2 lamps.

For the two rooms which are shown in Fig. 3, each room has one input and one output as defined and listed in Table IV.

TABLE IV: DEFINITIONS OF ALL INPUTS AND OUTPUTS OF A TWO ROOM DESIGN

Symbol	Definition
S_0	Sensor to detect human existence in room 1.
S_2	Sensor to detect human existence in room 2.
$L_0(t)$	Present state (on/off) of lamp in room 1.
$L_2(t)$	Present state (on/off) of lamp in room 2.
$L_0(t+1)$	Next state (on/off) of lamp in room 1.
$L_2(t+1)$	Next state (on/off) of lamp in room 2.
L_{i0}	Intermediate output to put lamp on/off in room 1 permanent.
T_0	Intermediate output to put lamp on/off in room 1 limited time.
L_{i2}	Intermediate output to put lamp on/off in room 2 permanent.
T_2	Intermediate output to put lamp on/off in room 2 limited time.

For two rooms, we have two inputs ($S_0 \& S_2$) and two outputs ($L_0(t+1) \& L_2(t+1)$). We aim to design a HEMS which is based on logic circuits to control the lighting of the two rooms according to the following conditions:

1 If a person exists in room1 or room2, the lamp inside the corresponding room is turned on permanently.
2 If a person leaves any room, the lamp inside the room is left on for a limited time and then turned off.

The equations of the design can be applied during nighttime by introducing $\overline{S_1}$ and can be used during sunlight time by introducing S_1 as discussed in subsection II. A.

The possibilities of the sensors S_0, S_2 and the outputs $L_0(t+1)$, $L_2(t+1)$ are listed in Table V which is composed of 11 columns. There are four inputs among which two regular inputs namely S_0 and S_2 and two input states $L_0(t)$ and $L_2(t)$. For the four inputs there are sixteen possible combinations for them. There are six outputs namely L_{i0}, L_{i2}, T_0, T_2, $L_0(t+1)$ and $L_2(t+1)$. L_{i0}, L_{i2}, T_0 and T_2 are intermediate outputs. L_{i0} and L_{i2} represent the signal to turn on the lighting of the lamps permanently incase a person exists in room1 and/or room2 respectively. T_0 and T_2 represent the signal to turn on the lighting of the lamps for a limited time in case a person leaves room1 and/or room2 respectively. All possibilities can be summarized in four scenarios for each room. The four scenarios are exactly the same as those for the one room design as shown in Table V.

TABLE V: STATE TRUTH TABLE FOR A TWO ROOM DESIGN

	Present (t)		Input		Intermediate Output				Next (t+1)	
#	L0	L2	S0	S2	Li0	T0	Li2	T2	L0	L2
0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	0	1	0	0	1
2	0	0	1	0	1	0	0	0	1	0
3	0	0	1	1	1	0	1	0	1	1
4	0	1	0	0	0	0	0	1	0	1
5	0	1	0	1	0	0	1	0	0	1
6	0	1	1	0	1	0	0	1	1	1
7	0	1	1	1	1	0	1	0	1	1
8	1	0	0	0	0	1	0	0	1	0
9	1	0	0	1	0	1	1	0	1	1
10	1	0	1	0	1	0	0	0	1	0
11	1	0	1	1	1	0	1	0	1	1
12	1	1	0	0	0	1	0	1	1	1
13	1	1	0	1	0	1	1	0	1	1
14	1	1	1	0	1	0	0	1	1	1
15	1	1	1	1	1	0	1	0	1	1

For example, in possibility # 9, $L_0(t)=1$, $L_2(t)=0$, $S_0=0$ and $S_2=1$ stand for the present state of the lamp in room1 is on, the lamp in room2 is off, no person exists in room 1 and there is a person in room 2. This can mean that a person was in room1 and left it and entered room2. As a result, the intermediate outputs are $L_{i0}=0$, $T_0=1$, $L_{i2}=1$ and $T_2=0$ which stand for the lamp in room 1 stays on for a limited time and the lamp in room 2 stays on permanently. From Table V, we can see that the proposed system behaves exactly the same for each room. We can deduce that adding extra rooms to the system adds only a replica of the results mentioned. According to the conditions stated at the beginning of this subsection, the proposed system acts as predefined for it to function.

The possibilities listed in Table V are summarized in the mealy state machine shown in Fig. 4. Each circle contains two bits representing the present or next state of the outputs $L_0(t+1)$ and $L_2(t+1)$. An arrow is directed from a present to next state with the corresponding input (S_0 S_2) written on it.

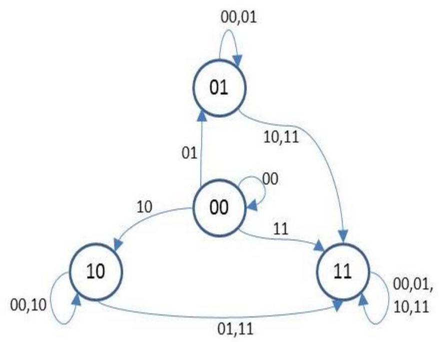

Fig. 4. Mealy state machine for a two room design.

For state 00, all arrows are going outside it except the arrow which feeds into the state itself. This is due to the fact that the system is designed to put light always on even if for a limited time unless the previous state of a room is off. For state 11, all arrows are going inside it except the arrow which feeds into the state itself. That is because, the light never goes off even if someone leaves the room, light stays on for some time and then goes off due to time limitations only.

Next, four 4-variable karnaugh maps are used to obtain the equations of the four intermediate outputs T_0, L_{i0}, T_2 and L_{i2} as shown in Table VIa, b and VIIa, b, respectively.

TABLE VI: 4-VARIABLE KARNAUGH MAPS FOR A TWO ROOM DESIGN
(A) L_{i0} (B) T_0

(a-Li0)

			S0	S0	
	0	0	1	1	
	0	0	1	1	L2
L0	0	0	1	1	L2
L0	0	0	1	1	
		S2	S2		

(b-T0)

			S0	S0	
	0	0	0	0	
	0	0	0	0	L2
L0	1	1	0	0	L2
L0	1	1	0	0	
		S2	S2		

TABLE VII: 4-VARIABLE KARNAUGH MAPS FOR A TWO ROOM DESIGN (A) L_{i2} (B) T_2

(a-Li2)

			S0	S0	
	0	1	1	0	
	0	1	1	0	L2
L0	0	1	1	0	L2
L0	0	1	1	0	
		S2	S2		

(b-T2)

			S0	S0	
	0	0	0	0	
	1	0	0	1	L2
L0	1	0	0	1	L2
L0	0	0	0	0	
		S2	S2		

From Table VIa and b, the equations of the intermediate outputs (T_0 & L_{i0}) are as follows:

$$T_0\left(L_0,L_2,S_0,S_2\right)=\overline{S_0}L_0 \tag{4}$$

$$L_{i0}\left(L_0,L_2,S_0,S_2\right)=S_0 \tag{5}$$

From Table VIIa and b, the equations of the intermediate outputs (T_2 & L_{i2}) are as follows:

$$T_2\left(L_0,L_2,S_0,S_2\right)=\overline{S_2}L_2 \tag{6}$$

$$L_{i2}\left(L_0,L_2,S_0,S_2\right)=S_2 \tag{7}$$

We can see that eqs. (4) and (6) are the same except that the equation of each room is expressed in its own parameters (sensor and lamp inside each room). Also, eqs. (5) and (7) are the same except that the equation of each room is expressed in its own parameters (sensor inside each room). We can deduce that increasing the number of rooms will only add an extra replica of the equations mentioned above and the relation between parameters doesn't change. The equations of the next state outputs $L_0\left(t+1\right)$ and $L_2\left(t+1\right)$ are as follows:

$$L_0\left(t+1\right)\left(L_0,L_2,S_0,S_2\right)=L_{i0}+T_0 \tag{8}$$

$$L_2\left(t+1\right)\left(L_0,L_2,S_0,S_2\right)=L_{i2}+T_2 \tag{9}$$

The logical relation between the parameters used in either eqs. (8) or (9) are the same. But the two equations are for different rooms and so different parameters are used in each. Next, we use Simulink in Matlab to simulate the above mentioned equations. We aim to verify that their output is as expected. Matlab is used as it is one of the most famous tools used in undergraduate educational laboratories and it suffices to study the simple designs which are addressed here.

III. SIMULATION RESULTS

In this section, we simulate the above mentioned equations and test if the results match what is expected using Simulink in Matlab software. In subsection A, the simulation for the equations describing the logic circuit for a house composed of one room is displayed. In subsection B, the simulation for the equations describing the logic circuit for a house composed of two rooms is displayed.

A. *One Room Simulation*

In this subsection, we divide each of the eqs. (1) and (2) into sunlight and night terms. The schematics of the terms T_{0_N}, L_{i0_N}, T_{0_S} and L_{i0_S} are drawn on Simulink. T_{0_N} stands for the term in eq. (1) which includes $\overline{S_1}$ and represents the part of the equation applicable during night time.

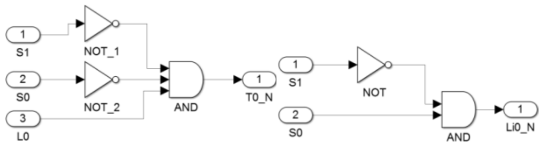

Fig. 5. (L): The circuit for the equation of T_{0_N} is shown on the left. (R): The circuit for the equation of L_{i0_N} is shown on the right.

This part is composed of one AND gate with three inputs and two NOT gates. The digital logic circuit representing the T_{0_N} function is shown in Fig. 5L. L_{i0_N} stands for the term in eq. (2) which includes $\overline{S_1}$ and represents the part of the equation applicable during night time.

This part is composed of one AND gate with two inputs and one NOT gate. The digital logic circuit representing the L_{i0_N} function is shown in Fig. 5R. T_{0_S} stands for the term in eq. (1) which includes S_1 and represents the part of the equation applicable during sunlight time.

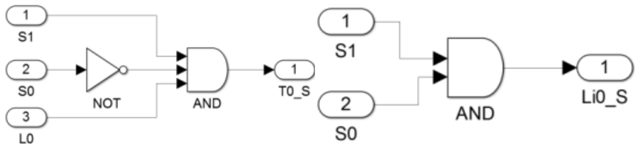

Fig. 6. (L): The circuit for the equation of T_{0_S} is shown on the left. (R): The circuit for the equation of L_{i0_S} is shown on the right.

This part is composed of one AND gate with three inputs and one NOT gate. The digital logic circuit representing the T_{0_S} function is shown in Fig. 6L. L_{i0_S} stands for the term in eq. (2) which includes S_1 and represents the part of the equation applicable during sunlight time.

This part is composed of one AND gate with two inputs. The digital logic circuit representing the L_{i0_S} function is shown in Fig. 6R. The four terms L_{i0_N}, T_{0_N}, L_{i0_S} and T_{0_S} form the terms of the equation $L_0\left(t+1\right)$ which is shown in Fig. 7.

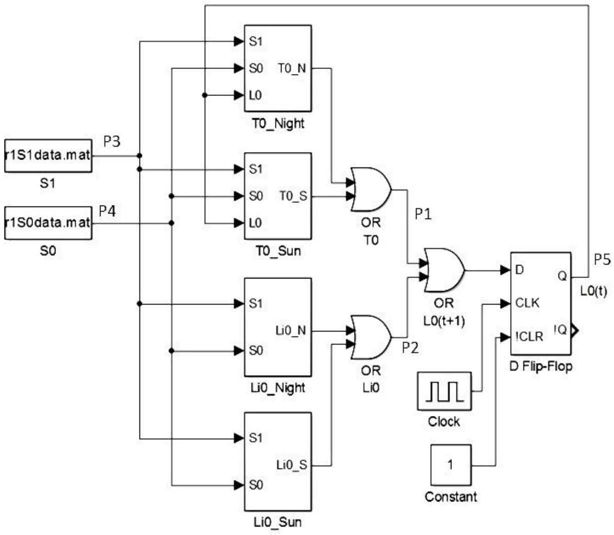

Fig. 7. The whole circuit for the one room design showing points at which probes (P1, P2, P3, P4, P5) are used to take readings.

Four boxes are seen in Fig. 7 arranged vertically on top of each other in the middle. Two boxes represent L_{i0} with its sunlight and night terms. Another two boxes represent T_0 with its sunlight and night terms. The OR gate representing T_0 was designed to give output response for a certain duration only. The outputs of the OR gates for L_{i0} and T_0 feed an OR gate with two inputs. The output of this OR gate, namely $L_0(t+1)$, is fed to a D flip/flop to generate the states. The simulation is run with inputs (S_0 & S_1) having values as shown in Table II so that we have one logic bit per second for each variable input. When the circuit in Fig. 7 is run on Simulink an error is identified. The results of the output $L_0(t)$ give infinite high to the lamp in room 1 once the blocks of T_0 have 1 on any of their outputs. The reason is that once $T_0=1$ and $S_0=0$, then the limited period of the lighting is infinitely triggered and so the lamp never goes off. The period of the clock of the D-flip flop has to be much longer than the time limit set by T_0 so that the system doesn't go through the infinite loop. The period of the clock has to be at least equal to double the time limit set in T_0. When this rule is applied, then the output results of the circuit shown in Fig. 7 are shown in Fig. 8. In Fig. 7, the probes P1, P2, P3, P4 and P5 are the points at which readings are taken to draw the graph in Fig. 8.

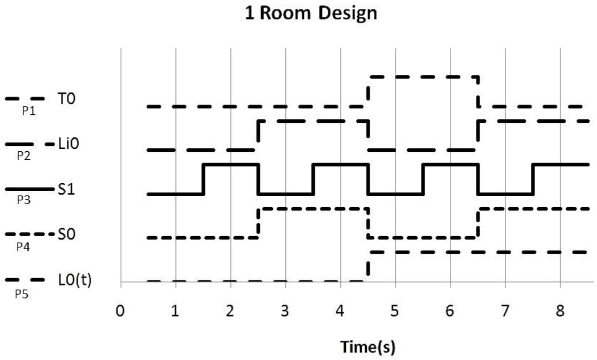

Fig. 8. Input and outputs of the logic circuit shown in Fig. 7 showing the probes at which readings (P1, P2, P3, P4, P5) were taken.

In Fig. 8, the T_0 line is the output of the logical OR-ing between the circuit in Fig. 5L and Fig. 6L. The L_{i0} line is the output of the logical OR-ing between the circuit in Fig. 5R and Fig. 6R. The output is as expected in Table II. The probes P1, P2, P3, P4 and P5 are written beside each line drawn in Fig. 8 to represent the corresponding point in Fig. 7 at which these readings were taken. The values of the intermediate outputs are determined according to the values of the inputs $L_0(t)$, S_0 and S_1. For example at $t=2$ seconds, $L_0(t)=0$, $S_0=0$ and $S_1=1$ which stand for the lamp is off, no person is in the room and the time is sunlight respectively. The outputs are $L_{i0}=0$ and $T_0=0$ which stand for the next state of the lamp is off. An Integrated Dimmer switch is used to control the energy delivered to the lamp to be full or half full [15]. It is controlled by the input from the daylight sensor S_1 as shown in Fig. 9.

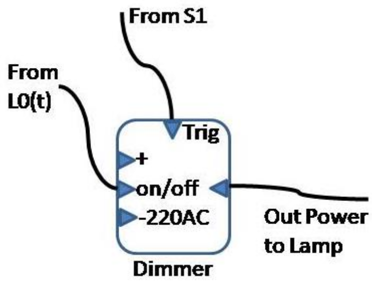

Fig. 9. A Dimmer is used to complete the design in Fig 9.

As seen in Fig. 9, the dimmer is controlled by four inputs and gives one output. The two inputs with positive and negative signs get input from the electrical plug (220V AC). The third input gets a signal from the $L_0(t)$ of the proposed HEMS to control the on/off switch of the dimmer. A fourth input gets a signal from S_1 to control the amount of output energy from the dimmer to the lamp. When $S_1=1$ (sunlight time) the output energy is fifty percent the value when $S_1=0$ (night time). The output of the dimmer is connected to the lamp. Next, we simulate the logic circuit for the two room design.

B. Two Rooms Simulation

In this subsection, the schematic of the terms T_0, L_{i0}, T_2 and L_{i2} is drawn using Simulink in Matlab. T_0 represents eq. (4) which is a part that is applicable when lighting is required for limited time in room 1.

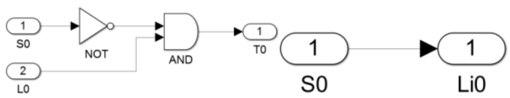

Fig. 10: (L): The circuit for the equation of T_0 is shown on the left.
(R): The circuit for the equation of L_{i0} is shown on the right.

This part is composed of one AND gate with two inputs and one NOT gate. The digital logic circuit representing the T_0 function is shown in Fig. 10L. L_{i0} represents eq. (5) which is a part that is applicable when lighting is required for permanent time in room 1.

This part is composed of no gates except a direct connection to the S_0 sensor. The digital logic circuit representing the L_{i0} function is shown in Fig. 10R. The two parts L_{i0} and T_0 form equation $L_0(t+1)$ which is shown in Fig. 11.

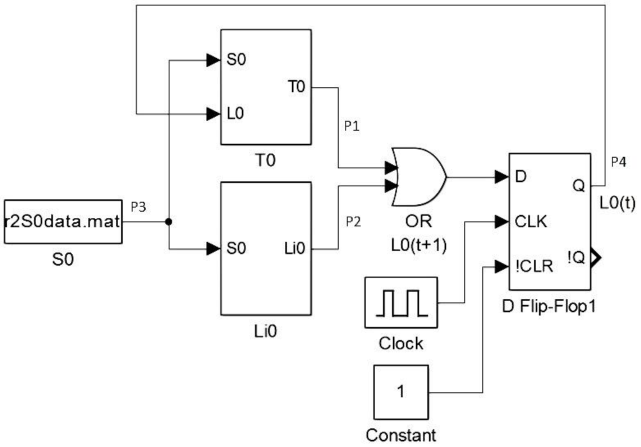

Fig. 11. The whole circuit for room 1 in the two room design showing points at which probes (P1, P2, P3, P4) are used to take readings.

Two boxes are seen in Fig. 11 arranged vertically on top of each other in the middle. One box represents L_{i0} which is shown in Fig. 10R. Another box represents T_0 which is shown in Fig. 10L. The outputs of the two functions feeds an OR gate with two inputs. The output of the OR gate ($L_0(t+1)$) is fed to a D flip/flop to generate the states. The implementation on Simulink of the circuit for room 2 is a replica for that of room 1. The simulation was run with inputs (S_0) having values as shown in Table V so that we would have one logic bit per second for the variable input. The output $L_0(t)$ of the circuit shown in Fig. 11 is shown in Fig. 12. In Fig. 11, the probes P1, P2, P3 and P4 are the points at which readings are taken to draw the graph in Fig. 12.

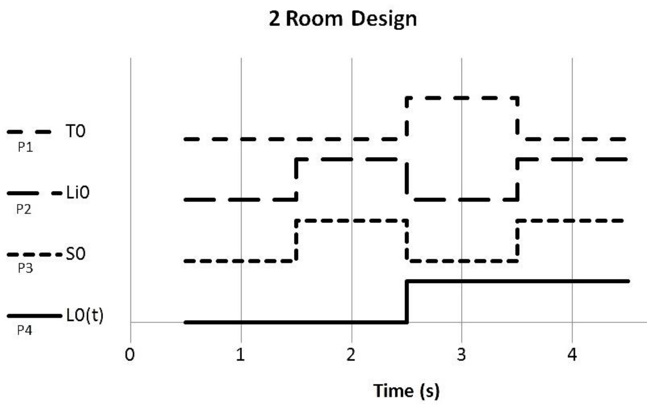

Fig. 12: Input and outputs of the logic circuit shown in Fig. 11 showing the probes at which readings (P1, P2, P3, P4) were taken.

The output is as expected in Table V. The values of the intermediate outputs are determined according to the values of the inputs $L_0(t)$ and S_0. The probes P1, P2, P3 and P4 are written beside each line drawn in Fig. 12 to represent the corresponding points in Fig. 11 at which those readings are taken. For example, at $t=2$ seconds, $L_0(t)=0$ and $S_0=1$ which stand for the lamp is off and no person is in the room respectively. In this case, the outputs are $L_{i0}=1$ and $T_0=0$ which stand for the next state of the lamp is on permanently. An Integrated Dimmer switch such as the one mentioned in Fig. 9 will be used for each room. our proposed solution revolves around the use logic circuits but when we come to applying it in real life application the output of the gates is interfaced through relays to control the switching of analog lamps. The output of the sensors is a digital signal which can be interfaced with the digital gates. Next, the amount of energy saved when the proposed HEMS is used inside a typical house is discussed.

IV. Calculation of Energy Saved

In this section, the energy consumption is calculated in a typical house and the method through which our proposed system can save energy is explained. The above proposed designs are used to control switching of lamps, but they can be extended to control the switching of Air conditioner, TV set or refrigerator. In this case we can study the savings in the energy consumption if the above proposed designs are used for every energy consuming product used inside a typical house as is discussed. We start by defining the rooms and the main electric appliances used in a typical house. Here, a house is addressed that is composed of three bedrooms, one Living Room (LR), one TV set, one refrigerator, three Hot Ventilation and Air Conditioning (HVAC) sets, one phone charger, one boiling set [13]. In addition, one set of our proposed HEMS system is installed inside the house which consumes some energy as well. Reference [13] described a HEMS system and calculated the energy consumed inside a typical house when such system is used. Stephen Makomin and Fred Popowike proposed a breakdown of the time of the day into active time, away time, and sleep time for a typical family to calculate the consumed energy for them [3]. This breakdown is applied in [13] and here. In Table VIII, we define the number of hours for the active, away and sleep modes as defined in [3].

TABLE VIII: Number of Hours per Three Modes Namely Active, Away and Sleep

Mode of Day	Active	Away	Sleep
Total Hr/Day	8	9	7
Sunlight(Hr)	3	9	1
Night (Hr)	5	0	6

We add in Table VIII two extra rows to mention the number of hours per each mode which falls within the sunlight time and night time. The main advantages for our proposed system are the sensing of the existence of humans inside the rooms and the sensing of the sunlight time. The extra rows are decided by our system and are used to calculate the saved energy. As an example, from the 8 hours allocated to the active mode, we can find that a person living in a typical house spends three hours out of them during sunlight time and five hours out of them during nighttime. Next in Table IX, we explain the distribution of the usage of the different rooms and appliances in the house during the different modes which are mentioned in Table VIII.

TABLE IX: THE ACTIVITIES DONE DURING EACH MODE OF THE DAY (S=SUNLIGHT, N=NIGHT)

Appliance	Active	Away	Sleep
TV	ON (6/8)	OFF	OFF
HVAC (LR)	ON (6/8)	OFF	OFF
Lighting	ON (3S+5N)	OFF	ON (1S+6N)

For example, the TV set in Table IX is not used at all during the away and sleep modes. But it is used for six hours out of the eight hours allocated for the active mode. Our proposed will not save energy, compared to other HEMS systems, for the phone charger, refrigerator, HVAC(Bedroom 1), HVAC(Bedroom 2), HVAC(Bedroom 3), washing machine, boiler and the operation power of the proposed HEMS system. All those rooms and appliances doesn't change their energy consumption by sensing the existence of human beings or sensing sunlight and night times. We put all of them under one category called rooms and appliances a shown in Table X and XI. Energy consumption in these categories is calculated in the same way as done in reference [13] so no changes happen to their values of consumption. In the other categories (TV set, HVAC (LR) and lighting) energy can be saved and so the details of their energy consumption are given.

TABLE X: QUANTITY, POWER RATING AND DUTY CYCLE OF APPLIANCES INSIDE A TYPICAL HOUSE

Appliance	Qty	PowerW)	Duty Cycle (%)
Lighting	8	30	25
TV	1	600	100
HVAC (LR)	1	1500	80

TABLE XI: POWER CONSUMED PER EACH ROOM AND APPLIANCE INSIDE A TYPICAL HOUSE

	Appliance	Mode of Day	Time(Hrs)	Daily (KWh)
1	Rooms + Appliances	-	-	43.27
2	Lighting	Active (Sun)	3	0.18
		Active(Night)	5	0.6
		Sleep (Sun)	1	0.06
		Sleep (Night)	6	0.72
3	TV	Active	6	3.6
4	HVAC (LR)	Active	6	7.2
			Total	55.63

In this section and the next section, the words energy and power are used interchangeably. From Table X and XI, we can find that the lighting of the lamps is done in the sleep and active modes. As defined before, the power delivered to the lamps during sunlight time is half that in nighttime. We assume that the number of lamps used is 8 lamps where each consumes either 30W or 60W [13] depending on the time of the day. The duty cycle of each lamp is 25% [13].

Then the daily power consumption can be calculated using the equation [13]:

$$Daily\_Power(KWh) = \frac{Qty \times Power(W) \times Time(Hrs) \times Duty\_Cycle(\%)}{100} \quad (10)$$

where Daily Power is the power consumption per day, Qty is the quantity of appliances, Power is the power rate of the appliance in watts and Duty Cycle is the percentage of power to be consumed. Applying eq. (10) on the lighting of the lamps during the sunlight time of the active mode, we find that the lighting of the lamps consumes the following power:

$$Daily\_Power = \frac{8 \times 30(W) \times 3(Hrs) \times 25}{100} = 0.18\ KWh$$

In another example, a typical house contains one TV set which consumes power equal to 600W. The set is used 6 hours per day out of the 8 hours allocated for the active mode and its duty cycle is 100%. For the TV set, the daily power consumption is:

$$Daily\_Power = \frac{1 \times 600(W) \times 6(Hrs) \times 100}{100} = 3.6\ KWh$$

Here, we assume that the daily power consumption is a representation of the amount of energy consumed. Same line of thought is applied to the HVAC that is located in the LR. The amount of power consumed for the HVAC (LR) is 7.2 KWh.The total amount of energy consumed for the whole house is 55.63KWh.

V. COMPARING RESULTS

When comparing our proposed system to the system mentioned in [13], we can find that our system has outperformed the other system in the three categories of lighting, TV set and HVAC in the LR. The information obtained by the sensors of our proposed HEMS enables our proposed system to save energy in the lighting category and the TV category. For the lighting category, the sensing of sunlight helps to reduce the consumption of energy by providing half of the amount of energy to the lamps as less light is needed by users due to the existence of sunlight. The manual light switch is always there if full light intensity option is needed. For the TV and HVAC categories, the sensing of the human existence helps to reduce the consumption of energy because a typical family spends some of its evening time in the kitchen and not in the living room which can be sensed by the human existence sensor. The TV and HVAC are closed off during this time.

TABLE XII: COMPARING POWER CONSUMPTION WITH OTHER HEMS SYSTEMS

	Appliance	Other System	Proposed System
1	Rooms + Appliances	43.3	43.3
2	Lighting	2.9	1.6
3	TV	9.0	3.6
4	HVAC (LR)	9.6	7.2
	Total Energy	64.8	55.6

In Table XII, we can see that our proposed system has reduced the amount of consumed power in the three categories by at least 25%. The total amount energy consumption has been reduced from 64.8 to 55.6KWh due to the application of the proposed system.

VI. CONCLUSION

The proposed system proved to be able to save energy consumption by almost 15%. The sensors which were used in the proposed system served in two things. The problem is addressed in its most simple version, but later paper addresses the cross talk between one system of sensors and another. The detection of sunlight time from nighttime has been used to make use of the sunlight as an indoors lighting source. Also, the detection of the existence of human beings inside the rooms or not has been used to put off the lamps, TV and the HVAC inside the rooms when they are not needed to save energy. The logic gates are one of the simplest kind of circuits which can be used to build a HEMS system and has proven their success. A detailed study of the usage of the rooms and appliances in a typical house is to be done in future work. The study can help to define areas at which the proposed system could save more energy.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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