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Design and simulation of an automatic room heater control system

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Abstract

This paper presents the design and simulation of an Automatic Room Heater Control system. This system allows the user to set a desired temperature which is then compared to the room temperature measured by a temperature sensor. With the help of a microcontroller, the system responds by turning ON any of the two (2) loads (Fan or a heater) automatically depending on the temperature difference. The Fan is triggered ON when the room temperature is higher than the set temperature and the heater is triggered ON when the room temperature is lower than the set temperature. The system was designed and simulated using Proteus 8, circuit building software used for building electronics system. Proteus software was used to design and simulate the main circuit, and Micro-C hex file was loaded on the Proteus schematic design. For coding the PIC Microcontroller, Micro-C compiler was used. A 5 V DC power supply was designed in order to provide a biasing voltage to most of the active devices used in the system design circuit. The DC power supply was designed and simulated using Multisim software. The system was simulated and simulation results were in accordance to the design specifications.

Keyword: Electrical engineering

1. Introduction

With the advancement of technology, automation has become part of our lives. A home is usually the most occupied place in any culture. Areas in the home that are usually occupied by people, such as the living room and bedrooms need to be maintained within habitable temperature ranges. These issues become more pertinent in areas of the home that are occupied by infants. Adults could possibly find their way around “thermal discomforts”, but infants may not. Other areas of the home that are used as storage areas for perishable food items also need to be thermally regulated in order to prevent accelerated decay of such items. This makes it necessary the need for a Temperature Control System within the home.

The idea of programmed room heater control systems goes back in the eighteenth century and this thought was first secured in Norman School, Oklahoma by an educator named Warren S. Johnson [1]. Before that time, Janitors were compelled to go in every classroom to check the temperature of the classes, and after that, control the dampers in the S-basement in like manner. Johnson looked for an approach to end, or possibly limit the classroom intrusions of the janitors and increment the solace level of the understudies [1]. The Automatic Temperature Control System was to meet this very need which prompts Warren S. Johnson stopping instructing and beginning his electric administration organization which was gone for outlining programmed control systems. Warren S. Johnson initially built up the pneumatic temperature control framework which took into account temperature control on a room by room premise in structures and homes. By the mid twentieth century the Automatic Temperature Control System creation ended up noticeably famous in enterprises and homes. As of late, a considerable measure of work is being finished by organizations in this field. A great deal of automatic room heater system business items is promptly accessible in the market and this includes devices such as AIR-CONS [1].

Weather is forever varying and changes on short intervals, and as a result, the external conditions always have an influence on the indoor conditions. The temperature control systems that are currently in use have limitations. One of these limitations is that the user has to adjust the system every time the external conditions change. This is very tiring and proves out not to be an effective way of controlling temperature of a room. Also, disabled people get to face a lot challenges when they want to operate temperature control system in their houses because this systems require them to use physical contact or some hand remote devices to operate them. To reduce the need to do this, a system that works automatically needs to be put in place.

This paper presents an automatic room heater control system. This is an air-conditioning system which monitors the room temperature and controls the

circulation of fresh air inside the room without human intervention. This design uses a microcontroller and a temperature sensor to monitor and control the temperature of a room. At first, the user will have to set the system temperature to a reference value that he or she wants to maintain in that room. The temperature sensor will then sense the surrounding temperature and communicates with the microcontroller. The microcontroller reads the temperature every 10 s and compares it with the desired value. If the measured value is less than the desired value, then the heater will be automatically triggered ON to warm up the temperature of the room until it returns back to the desired value and turns OFF. Also, if the measured value is greater than the desired value, then the Fan will be automatically triggered ON to cool up the temperature of the room until it returns back to the desired value and turns OFF. This work tends to design a simple but efficient system to solve a complex system. The need for simple and cost effective system tends towards the aspect of engineering design that looks into simple solutions that solve complex systems and also minimizing cost of designing a system by minimizing equipment and components in design. This is an aspect of the 10 Principles of Sustainable and Cost-Effective Design [2].

2. Related work

In the past few years, the need for automation has increased and has been widely applied to cooling and heating systems. There are plenty of commercial temperature control systems which can be bought from manufacturers or from inventors, and also, quite a lot of work have been published in this area. Our work is similar to the work in [3], if the measured value is greater than the desired value, the cooler/fan will be turned ON to cool the room temperature back to the normal set point and turns OFF once it is at that set point [3]. But it differs in the sense that, our work take into account, the ease of programming the microcontroller and user-friendliness by using keypad to enter a reference value. Hence, there is no need for experts after first programming of the microcontroller, thus, our system can be used by any one. In [4], Ian Bell invented a self-programmable heating and cooling system, which is based on temperature control system. This system is not easy to operate as it has to be interfaced with a computer anytime the re-programming is needed. In a related invention [5], R.E. Hedges invented an automatic temperature control systems intended at automatically controlling the temperature of an object, a part thereof, or a region so as to continuously maintain the said temperature at a constant value. In his design, the temperature control system can only control a single heat source; however, it is difficult to attain temperature control having simultaneously and in combination of the desirable features of large capacity, high response, and accuracy. M. R. Levine [6] invented an automatic temperature adjusting system for an air conditioner room. The automatic temperature adjusting system for the air

conditioner room was made simple in operation and was capable of monitoring the temperature of the human body at any time in the air conditioner room and transmits the corresponding signals to the air conditioner in time, and then the air conditioner conducts adjustment, so that health of people is guaranteed. However, this is also one time programming and it is needed to be interfaced with the computer anytime re-programming is needed, hence, the operation of the system becomes complex. Although a number of similar temperature control system, “do-it-yourself” temperature control designs have recently been published [5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16], these designs are not easy to use in term of programming and temperature adjustment. The systems work on the benefits of using temperature adjustable and fan temperature control systems. These systems are either one time programmable or need analog adjustment which is not accurate and more difficult to use. More recent, real time based temperature control using Arduino [17] was published. The system uses Arduino based on ATMELEL 89C51, which is just one of the application of Arduino, hence, not original design work, more expensive, and time consuming as one is needed to first learn the Arduino IDE. The system is also not simple in terms of operation as it does not provide the user a pad to change the reference temperature, hence, the system is just like the former that required computer interfacing for programming any time the reference temperature is needed to be changed. The system is similar to the ones presented by the authors in [18,19] that are also not easy to learn and use.

Other works based on temperature control do exist in different areas and different applications. Such work such as electric cable interference temperature monitoring in power transmissions [20], server room temperature measurement using Bluetooth embedded system [21], control system for communication room using wireless temperature monitoring system [22] and temperature sensor and Zigbee based temperature measurement [23,24] do exist. These systems have the same problem of cost as well as the need for experts in re-programming.

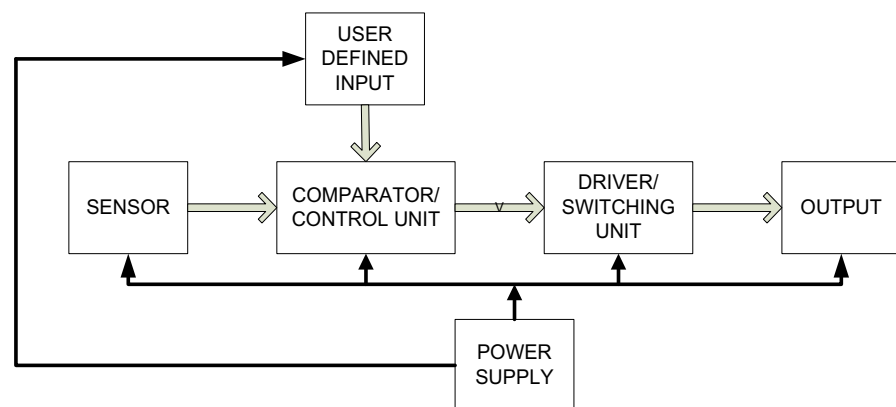


Fig. 1. Block diagram showing the major parts of the system.

3. Materials and methods

3.1. The automatic room heater control system

The Automatic Room Heater Control System comprises of three (3) main subsystems: Power supply unit, the Sensor unit and the Control/Switching unit as shown in the system block diagram in Fig. 1.

Fig. 1 consists of six (6) different blocks, each housing several components: Transmitter and Receiver subsystems. The sensor block consists of a temperature sensor

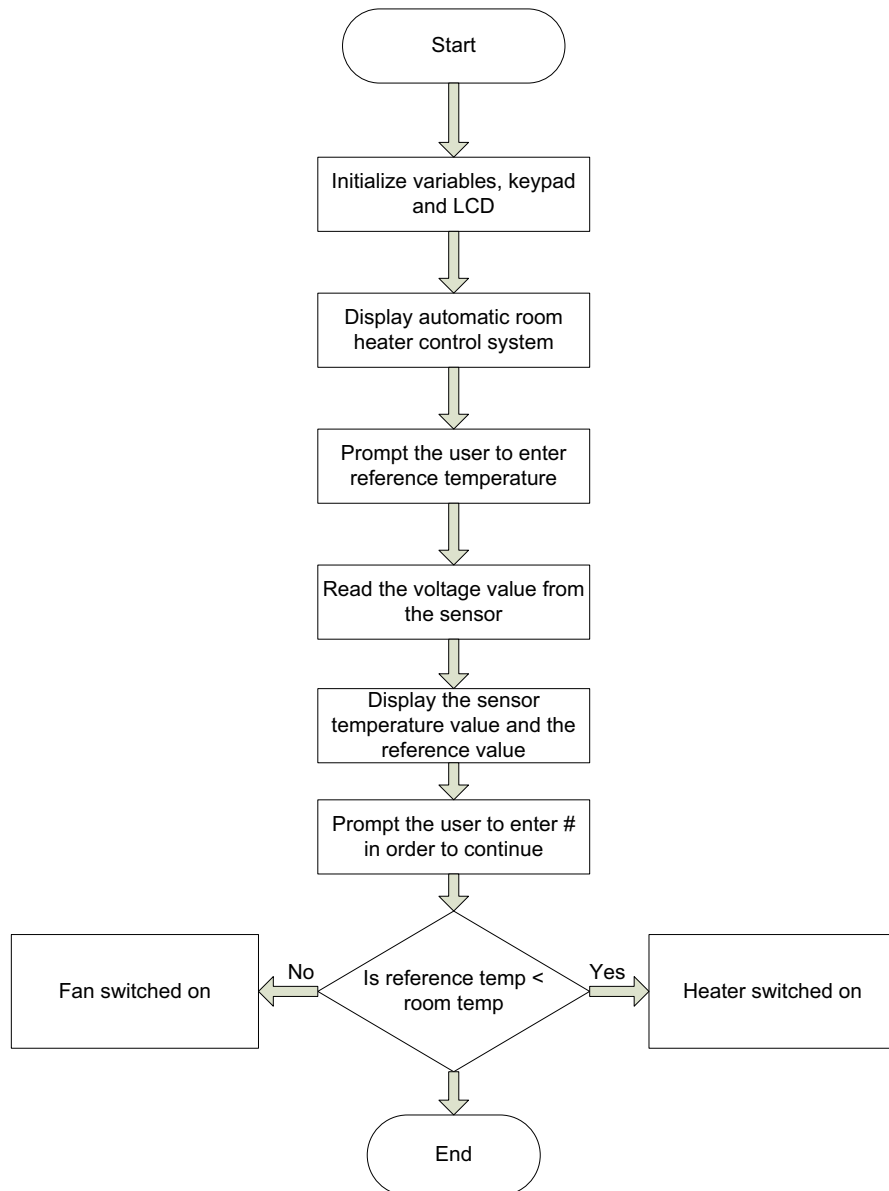


Fig. 2. System flow chart.

(LM35), the user defined input consists of a keypad, the comparator or control unit which is basically the heart of the system that consists of the microcontroller. Generally, the system circuit comprises of the PIC16F877A micro-controller, LM35 temperature sensor, LCD display, Crystal oscillator, 4 by 3 keypad for display, 2 transistors for switching purpose, 2 relays also used to support the transistor in the switching effect, a bulb modelled as a heater and a DC fan. The microcontroller is clocked by the crystal oscillator as it does not have an internal clock. Connected to the microcontroller is a temperature sensor LM 35 which measures the room temperature and give the value reading to the microcontroller. The 2 loads of the microcontroller switched on and off by the relays. The relays are not directly connected to the microcontroller but rather transistors as switches are place in between the microcontroller and the relay to prevent the relay from damaging the microcontroller. The resistors connected in every component of the system are used to limit the amount of current passing to that particular component. The LCD is connected to the microcontroller for displaying the data feed into the microcontroller. Fig. 2 gave the logical operation of the automatic room heater control system (flow chart). The brightness of LCD is controlled by the variable resistor as shown in Fig. 4. The complete list of the materials used for the system is shown in Table 1 as:

Table 1. List of materials.

Name of Component	Description
Step down transformer	20:1 (240/12 V, 1000 mA)
Rectifier Diode	1N4001*4
Resistors	220 Ω , 1 k Ω *2
Voltage regulators	7805, 7812
LEDs	Red *2 and Green *2
Electrolyte capacitor	3300 μ F and 4700 μ F
Switch	On and off push button
PIC16F877A microcontroller	PIC16F877A microcontroller
Crystal Oscillator	8 MHz Crystal Oscillator
Temperature sensor	LM 35 Temperature sensor
Relay	(12 V, 3 pin relay)*2
Transistor	BC108*2
Light Bulb	60 Watts, 240 V
DC Fan	12 V DC Fan
Resistor	(10 K)*6
LCD Display	LM016L (16*2) LCD Display
Keypad	4*3 Keypad
Variable Resistor	10 k Ω
Reset push button	Micro switch
Capacitor	22 pF

3.2. Power supply

The power supply was designed considering the available resources while meeting the design specifications. Most of the components operates on 5 V DC, while relays operating at 12 V were used, hence the need to step down the normal power supply voltage from mains (Approx. 240 V AC), to a reasonably voltage that will have to be rectified (convert to DC) and further filter to remove unwanted pulsation. The 240 V AC power was stepped down to 12 V AC (12 V RMS value wherein the peak value is around 17 V) as can be seen from the calculation that follows, the 17 V was further regulated using a voltage regulator (LM7805) to 5 V and (LM7812) to 12 V. A transformer of turn ratio of 20:1 was used after calculation for the purpose of stepping down the voltage and rectifier diodes (IN4001) were also used for rectification. Equations (1), (2), (3), (4), (5) give the process of obtaining a smooth DC signal (voltage).

From the turn ratio and power supply relationship of a transformer;

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}, \text{ i.e. } \frac{N_P}{N_S} = \frac{240}{12} = \frac{20}{1} = 20 : 1 \quad (1)$$

$$V_{RMS} = V_S = 12V \quad (2)$$

$$V_P = V_S \times \sqrt{2} = 12 \times \sqrt{2} = 16.9705 \approx 17V \quad (3)$$

Assuming a ripple voltage of 20%

$$dv = \frac{20}{100} \times 17 = 3.4V \quad (4)$$

$$df = \frac{1}{2f} = \frac{1}{100} = 0.01$$

$$C_1 = \frac{1 \times 0.01}{3.4} = 2.94 \times 10^{-3}F \quad (5)$$

A preferred value of 3300 μ F was however employed for the filtering of the assumed ripples as the value is higher than the calculated value, hence will filter much more than expected. Fig. 3 shows the designed power supply circuit and the results gotten from simulation.

3.3. Sensing unit

This section of the system uses a temperature sensor (LM35). A temperature sensor is a device that is temperature sensitive, and it responds to changes in temperature. For the calibration of the temperature sensor, we use the linear modelling approach. As it was used as a basic temperature sensor, any change in temperature by 1 °C is

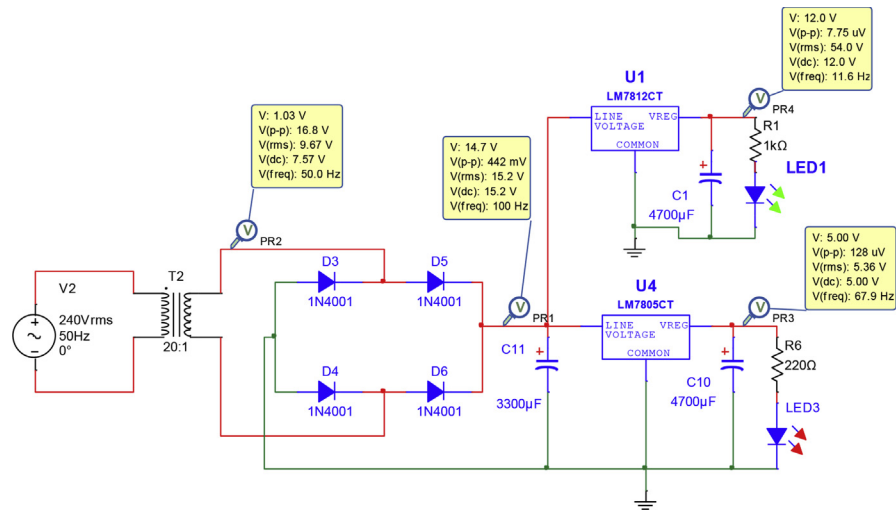


Fig. 3. Power supply circuit.

converted to 10 mV. The maximum voltage readout of the temperature sensor was 1 V corresponding to 100 °C. This was then used as a reference in programming the microcontroller. LM35 feed the microcontroller with an analog temperature voltage that is measured from the room. This analog signal is then converted to digital signal in the microcontroller because the microcontroller can only interpret digital data. LM 35 is connected to PORT A on the micro-controller because PORTA is Analog input pin by default. Although, the general relationship (Equations (6) and (7)) between the voltages drop at the pin 2 of the microcontroller gotten from the temperature sensor and the sensed temperature by the LM35-temperature sensor is given by [25]:

$$Temperature (^{\circ}C) = V_{out} \left(\frac{100^{\circ}C}{V_T} \right) \quad (6)$$

Or

$$V_{out} = Temperature (^{\circ}C) \times \left(\frac{V_T}{100^{\circ}C} \right) \quad (7)$$

Where V_T is the supply voltage and V_{out} , is the output voltage of the LM35 temperature sensor.

Though, from our code, we have declared how this temperature is going to be read and converted.

3.4. Control/switching unit

The Control/Switching unit houses the microcontroller which receives temperature status from the sensor unit. This unit consists of microcontroller, which uses PIC

16F877A microcontroller due to its reduced instruction set computer design. This also make it code extremely efficient, allowing the PIC to run with typically less program memory than its larger competitors such as 8081 based microcontrollers. It is also low cost in addition to its high clock speed. Other components and devices in this unit are: two (2) transistors and two (2) relays to switch ON and/or OFF a fan and or a heater. At first the user is prompted to input reference temperature that he or she wants to maintain in their room. The temperature sensor will then measure the surrounding temperature and communicates the value to the microcontroller. The microcontroller reads the temperature every 10 s and compares it with the reference value. If the measured value is less than the reference value, then the heater will be automatically be triggered ON to warm up the room until it returns back to the reference value and turns OFF the heater. If the measured value is greater than the reference value, the cooler/fan will be turned ON to cool the room back to the reference temperature and turns OFF once it's at that reference point again. The measured room temperature from the Temperature Sensor is analog in nature. The microcontroller has an in built Analog-to-Digital (A/D) converter which convert the analog signal into digital signal because the microcontroller is a digital device, and can only work with binary numbers. As shown in Fig. 2, is the system flow chart. The Pseudocode that leads to the coding of the microcontroller is as show in Pseudocode 1:

PSEUDOCODE 1: PIC 16F877A PSEUDOCODE

Initialize ports and variables
Read Temp from the analog sensor
Input Reference Temp
Display both the ACTUAL TEMP AND REFERENCE TEMP
COMPARE REF WITH ACTUAL
If Temp Ref is less than actual Temp, Switch ON Heater
If Temp Ref is greater than actual Temp, Switch ON Fan

The microcontroller was programmed using C language and the program was compiled using Micro C compiler. The code used as starting code before modification can be found in [26,27]. Micro C automatically generates the hexadecimal file (HEX) which was later exported into the Proteus file for simulation. Other aspect of the switching unit is the base biasing of the transistor.

Also, considering the switching circuit and to get a proper base biasing voltage of approximately 0.7 V since silicon based semiconductor, noting that the current from the output of the PIC16F877A microcontroller of output high and low voltages at source and sink currents of 7–8.5 mA (source) and 2.5–3.0 mA (sink), we can get the minimum value of current limiting resistor at the base of the transistor that will guarantee a base voltage of 0.7 V using Equations (8) and (9) as:

$$V_b = I_b \times R_b \quad (8)$$

This implies that,

$$R_b = \frac{V_b}{I_b} = \frac{0.7}{2.5 \times 10^{-3}} = 280\Omega \quad (9)$$

For a wider protection, we choose an appropriate value of 10 k Ω , since the minimum value to be used as gotten from the Equation (9) is 280 Ω . The complete circuit diagram showing all the design work of this value is shown in Fig. 4.

4. Results and discussion

We have conducted testing of our designed system (Automatic Room Heater Control system) via simulation using Proteus and Multisim software. From Fig. 3, it is seen that the calculated results agreed with the simulation results. From PR2 in Fig. 3, it is seen that $V_{RMS} = 9.76V$, though the value not exactly equal to the calculated result, but approximately equal to the value. If we then compare the peak voltage of the simulation result, (16.8 V), the value is approximately equal to the calculated value of 17 V as can be seen in Equation (3). As can be seen from the Fig. 3, U1 and U4 gave +12 V and +5 V respectively when deployed voltage regulators (LM7812 and LM7805).

Fig. 5 shows the relationship between the sensed temperature by the temperature sensor (LM35), and the output voltage, which is fed to pin 2 of the microcontroller

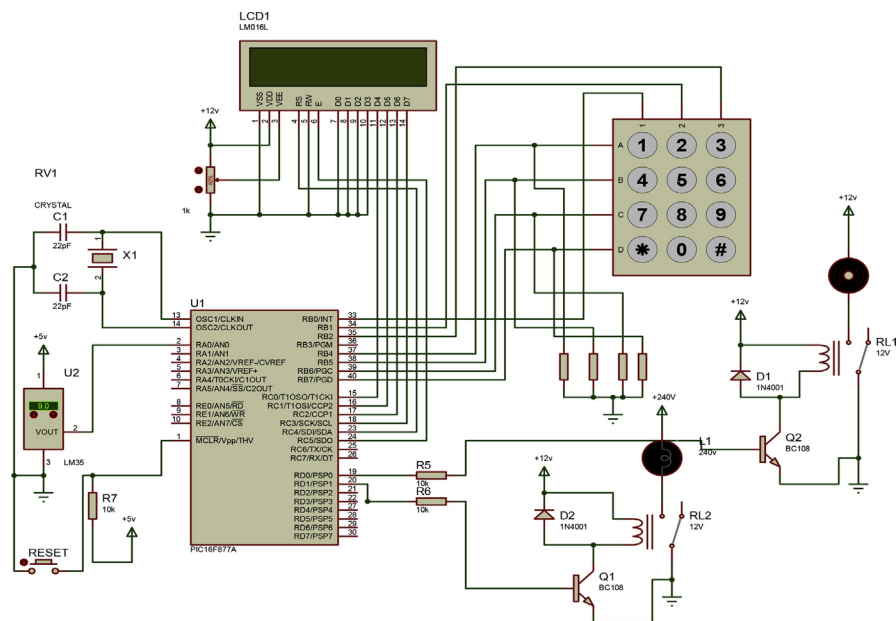


Fig. 4. Circuit diagram of Automatic Room Heater Control showing all components of the system.

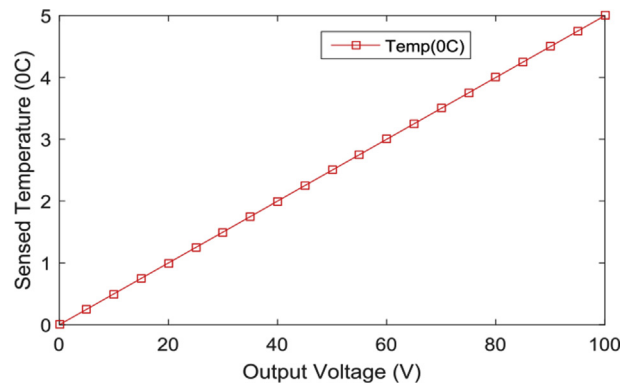


Fig. 5. Result of sensed temperature and the output voltage of the temperature sensor.

for the control purpose of the fan or heater system. As can be seen, the relationship is linear and one can easily control the output of the microcontroller via the output voltage of the temperature sensor.

In Fig. 6, we shows the result of a user prompted to enter reference temperature. The microcontroller reads the temperature every 10 s and compares it with the reference value. As can be seen, both RL1 and RL2 are disconnected from Lamp (L1) and the fan as loads. In Fig. 7, user entered 12 as the reference temperature, which is higher than the room temperature (9.27 °C), as can be seen from temperature sensor (LM35). But in this case, the microcontroller had not sent any signal to both loads since the user has not press the hash key to enter the value (12). For Fig. 8, the room

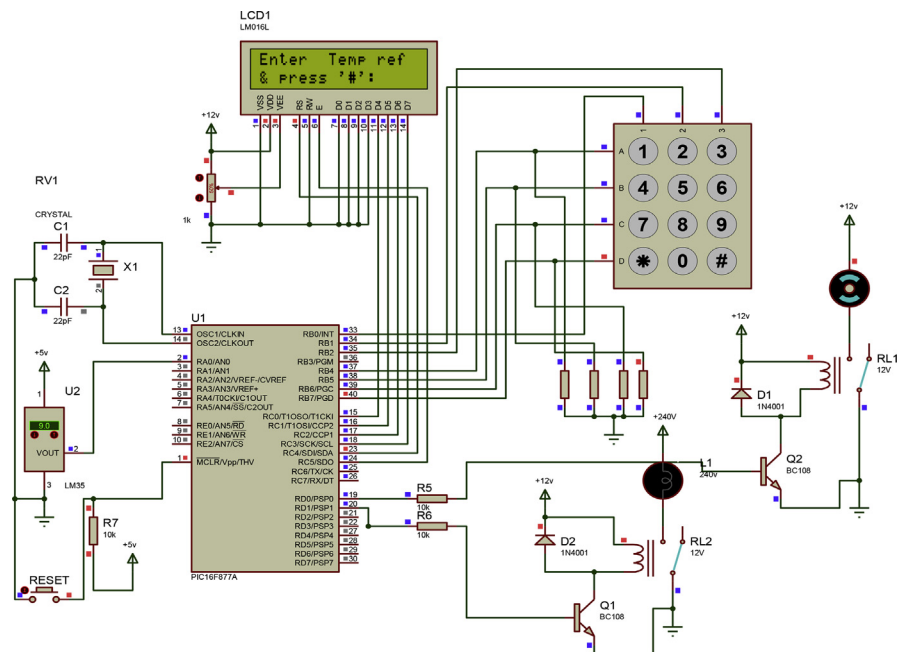


Fig. 6. Result of User prompted to enter a reference temperature.

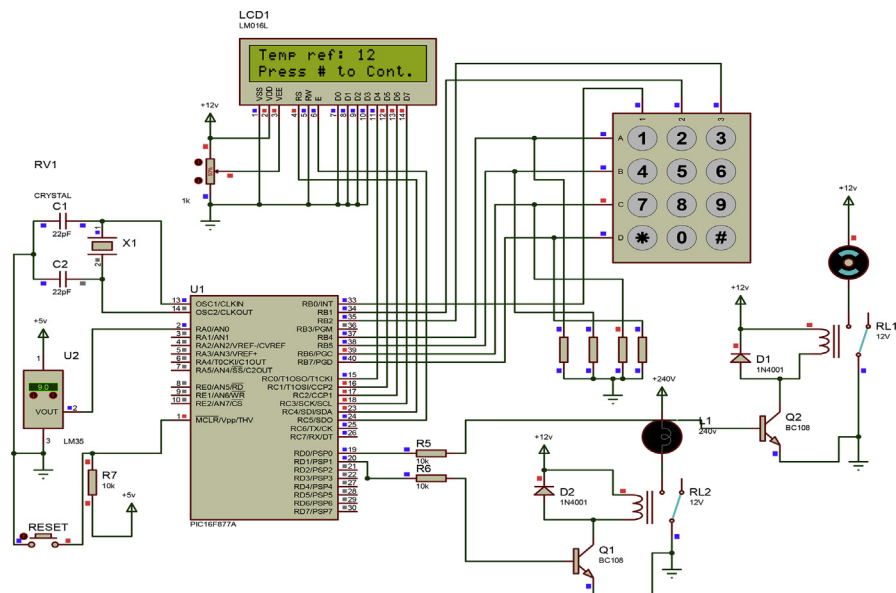


Fig. 7. Result of User entered 12 as the reference temperature.

temperature measured by the TEMP sensor is 9.27°C and the REF temp is 12°C . The microcontroller compared the two temperatures and switches the heater ON since the Reference temperature was higher than the room temperature; this is when the user has pressed the hash key. As seen from the Fig. 8, the Bulb is ON as an indication that the heater has been triggered on. Fig. 9 shows the result

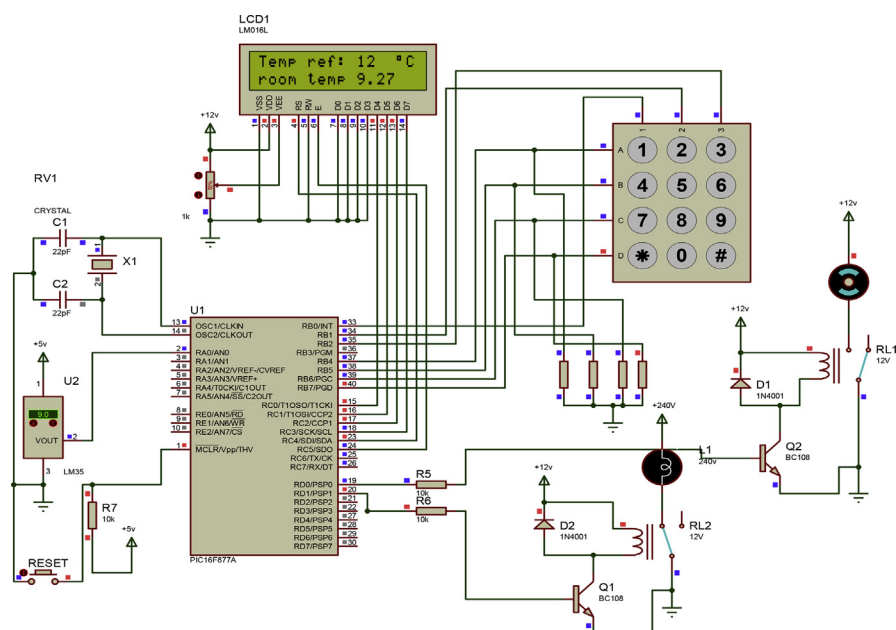


Fig. 8. Result of User entered 12°C as the reference temperature and Heater (L1) switched ON.

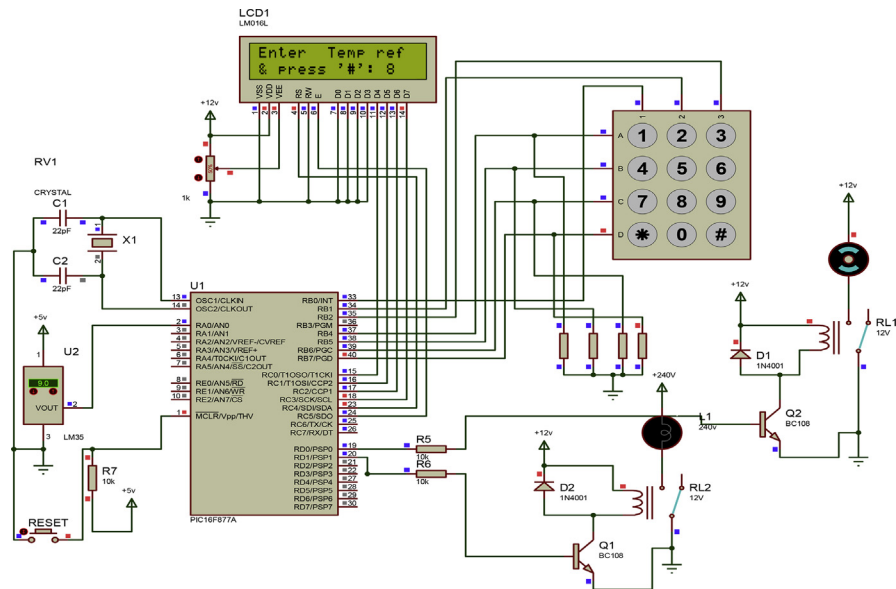


Fig. 9. Result of User entered 8 °C as the REF temp, and then entered # on the keyboard to continue.

when the user has entered 8 °C as the reference temperature, but the hash key has not been entered, which means the microcontroller has not been instructed to compare results. Also, from Fig. 10, when 8 °C and was entered as the Reference temperature and hash key pressed and the Room measured to be 9.27 °C, the microcontroller again compares the 2 temperatures values and turn on the Fan because the Reference temperature is lower than the Room Temperature.

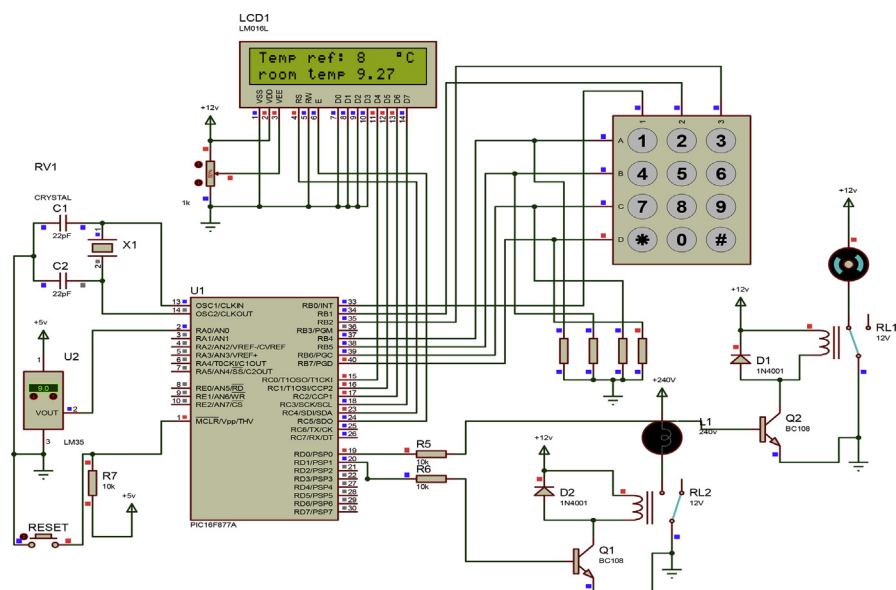


Fig. 10. Result of User entered 8 °C as the reference temperature and Heater (L1) switched ON.

5. Conclusions

In this paper, we present the design, simulation and analysis of an Automatic Room Heater Control System. The system uses PIC 16F877A microcontroller for the control unit and LM35 as the temperature sensor. The output was varied by setting the temperature at various levels and it was discovered that the Fan was triggered ON when the room temperature was higher than the reference temperature and the heater was triggered ON while the Fan triggered OFF when the room temperature was lower than the reference temperature. The system is exceptionally helpful for people who are disabled. This system can be used in the industry or any enclosure where temperature is needed to be maintaining at a particular value. The system was designed using Proteus and Multisim Software. The system was simulated and working according to the design specifications. In future a GSM module can be integrated with the system so that one can be able to operate their temperature control system from a distance.

Declarations

Author contribution statement

Adamu Murtala Zungeru, Mmoloki Mangwala, Joseph Chuma, Baboloki Gaebolae, Bokamoso Basutli: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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