UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

ELEN2001: Indoor Pool Climate Controller Project Report

Group 34:

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Sansha Gupta (1619757) - Bathing Load

Jonathan Taylor (1665909) - Internal Lights

Blake Denham (1714988) - External Lights

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Abstract: This project's objective was to design and demonstrate an indoor pool control system involving a power supply, bathing load counter, lighting, humidity and temperature control. This was achieved through distinct stages of research, calculation, simulation and measurement of each component in an iterative process to achieve the final complete solution. Results showed that this project worked in practice as designed. This project's conclusion was that a successful solution to the problem it was designed to solve, but it could be improved by making each component more stable and predictable.

1. INTRODUCTION

For many, a controller for an indoor pool is one of the biggest desires of modern day living. It is important to ensure the perfect level of comfort when relaxing on the weekend with your family and friends. Unfortunately, many professional solutions for this are very expensive in terms of the actual components required and maintenance. Fortunately, the ability to effortlessly model the power, entrance, lighting, humidity and temperature was the goal of this project. Each of these individual component were tirelessly and frugally designed and built by different students which were then assembled together to create a powerful and efficient solution. This solution could be scaled and used to model real pool systems, ensuring R & D costs decrease and many more people can afford pool control systems. Furthermore, each system operates using only the fundamental building blocks of electronic components. Further progress could be made by making each individual system work more stably together to ensure a longer operating period of the solution.

2. POWER SUPPLY: VICTORIA BENCH(1611349)

2.1 Requirements

A multiple output DC power supply is required for the operation of the entire system. This subsystem converts the AC main power supply into a series of stepped-down DC voltages. The Bathing Load subsystem requires 5V, Humidity Control requires 6V, Lighting requires 9V, while Temperature Control requires a dual-power supply of ± 9V.

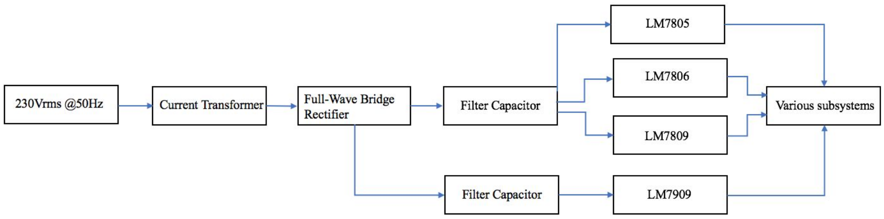

Figure 1: Block Diagram describing the circuit's functionality.

2.2 Design

Figure 1 displays the order in which 230Vac @ 50Hz is converted into 5V, 6V, 9V and –9V DC using a current transformer, full-wave bridge rectifier, filter capacitors and various voltage regulators in order to power the different subsystems [1].

2.1.1 Transformer: The largest voltage that the subsystems require is +/- 9V. Therefore, the 1A multiple voltage output current transformer should supply a voltage with a peak greater than 9V + 1.4V to account for the voltage drop across the rectifier at any given time. The subsystem circuits also require very small amount of current, thus, the 12V pin of the transformer is used as it supplies sufficient voltage and current when a Thevenin equivalent load is connected.

2.1.2 Full-wave Bridge Rectifier (FWBR): Four 1N4007 rectifier diodes are connected in a bridge configuration as seen below in Figure 2. These specific diodes are used because of the high peak repetitive reverse voltage rating of 1000V[2]. A 1000mF electrolytic filter capacitor is used at each terminal of the FWBR to further regulate the pulsating DC current outputted by the FWBR [1]. The maximum voltage rating of the filter capacitors used is 50V to ensure that the rating will not be exceeded easily [3].

2.1.4 Voltage Regulators: A LM7805, LM7806, LM7809 and LM7909 are used to maintain constant output voltage and suppress any unregulated voltage ripple. A bypass capacitor is placed in parallel with each voltage regulator for an improved transient response. A 1mF tantalum capacitor is used for this purpose as it has low impedance even at low frequencies [4].

2.2 Results and Evaluation

Testing was carried out using 2W 1kW load resistor. In reality, the subsystems draw much less power from the power supply. As seen in Figure 2, a second LM7805 voltage regulator is used in simulation due to the lack of a LM7806.

As shown in Table 1, the power supply circuit is able to power all the 2W 11kW resistors without blowing, outputting the appropriate voltages differing by no more than 1.2% from the theoretical voltage output.

Table 1: DC Voltage (V) and current (mA) outputs from different voltage regulators when connected to a 2W 1kW resistor.

	LM7805	LM7806	LM7809	LM7909
Theory	Vo = 5.00V Io = -5.00mA	Vo = 6.00V Io = -6.00mA	Vo = 9.00V Io = -9.00mA	Vo = -9.00V Io = 9.00mA
Simulated	Vo = 5.00V Io = -5.00mA	n/a	Vo = 8.98V Io = -9.07mA	Vo = -9.07V Io = 9.09mA
Tested	Vo = 5.00V Io = -3.76mA	Vo = 5.89V Io = -4.31mA	Vo = 8.87V Io = -7.98mA	Vo = -9.01V Io = 8.51mA

During the practical assessment, the power supply was able to power all the subsystem circuits at one time.

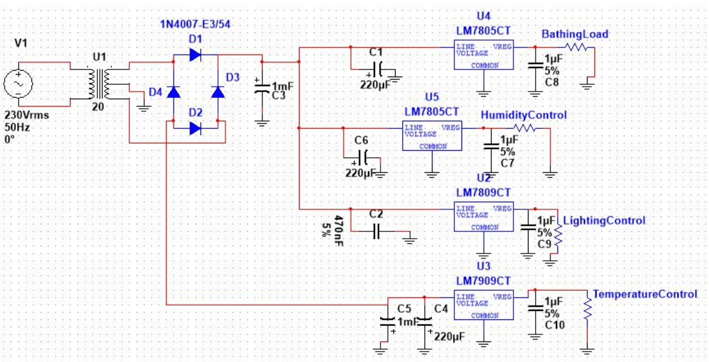

Figure 2: Power Supply circuit diagram simulated and built.

2.2.3 Recommendations: Current limiting resistors could be introduced to avoid too much current being supplied to a subsystem with the potential of damaging it. The addition of a fuse to prevent the transformer from short circuiting on the occasion that the filter capacitor fails would also be advantageous.

3. BATHING LOAD: SANSHA GUPTA (1619757)

3.1. Requirements

The bathing load subsystem is responsible for controlling and limiting the amount of patrons in the pool area at one time. The subsystem requires input from gap sensors which simulate patrons entering or exiting the pool area. It also requires 7 segment displays to display the number of patrons in the pool area, incrementing or decrementing when a patron enters or exits the pool area, respectively (not including any lifeguards or staff). The number of patrons allowed entrance are limited to the specified bathing load of 82.

3.2. Design

The subsystem requires 5V of DC power from the power supply and the components are connected as illustrated in Figure 3.

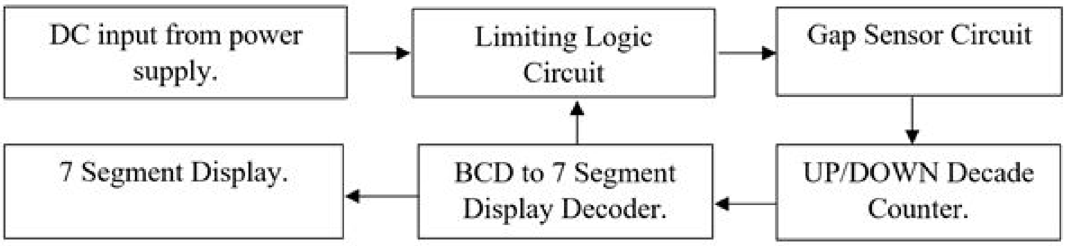

Figure 3: Block diagram illustrating the connection of components.

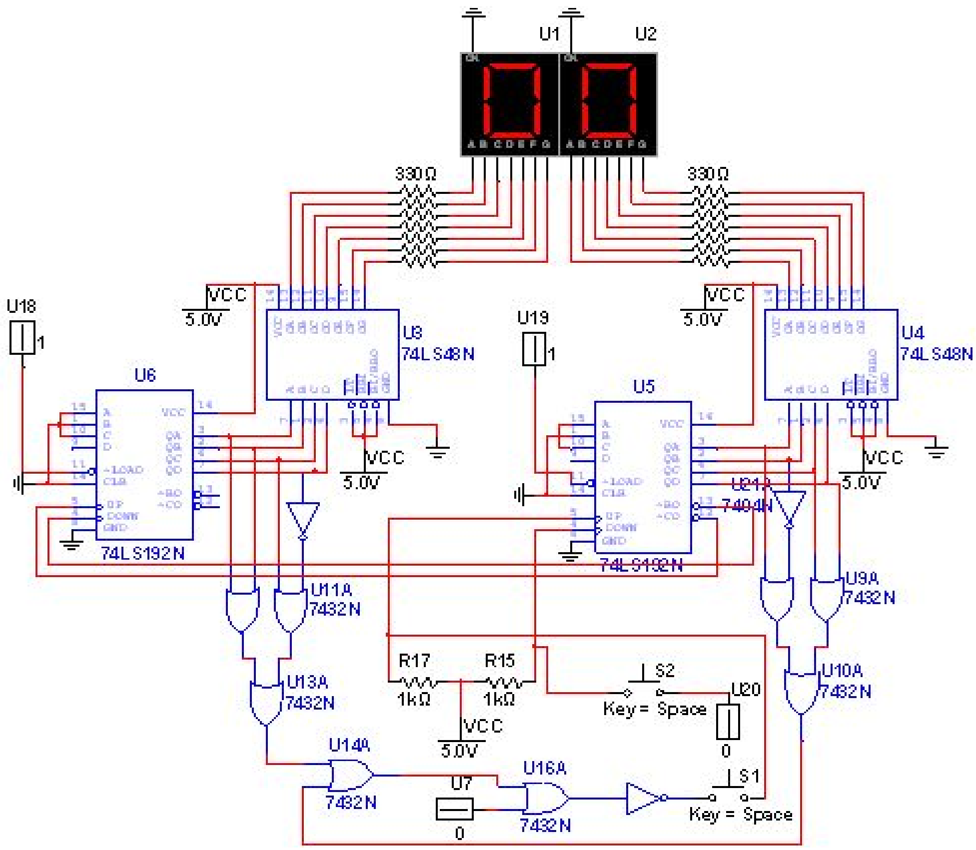

Figure 4: Circuit Diagram for bathing load.

Figure 4 illustrates the circuit diagram and how the 7-Segment displays are connected. The 7-Segment displays are common cathode configurations and hence the 74HCT192 Up/Down decade counter and 74LS48 BCD to 7-Segment IC chips are used. The 74HCT192 counter requires a low (digital) input to count [5]. resistors are used to protect the LEDs in the display and keep the current through the display in a low range (mA).

3.2.1 Gap Sensor Circuit

The gap sensor (TCST2103) operates using an LED which emits light and a phototransistor which detects the light being emitted. A 100Ω resistor is used to limit the current through the LED as shown in Figure 4 [6]. The 100Ω and 10kΩ resistors are also used to set the voltage at the input below 0.8V and above 2.4V which generates the negative edge clock pulse required by the decade counter (74HCT192) to count. The hex Schmitt Trigger Inverter (74LS14) is used to debounce the input signal so that no false switching occurs [7].

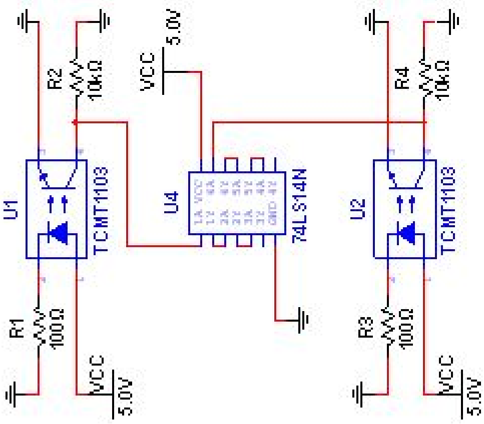

Figure 5: Circuit Diagram of Gap Sensor.

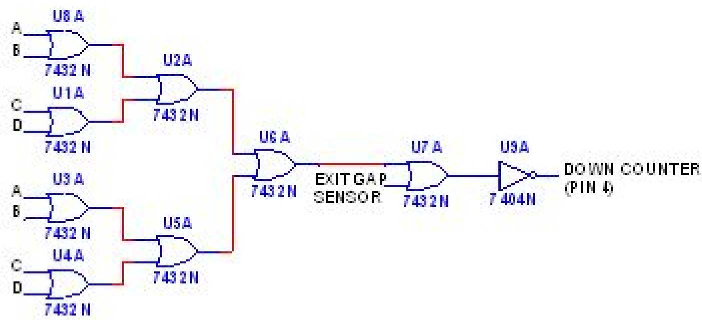

Figure 6: Circuit Diagram to limit down counter.

3.2.2 Limiting Circuit

The limiting circuit has two parts. Part 1 limits the counter from exceeding the bathing load using OR gates and NOT gates as depicted in Figure 4. Part 2 limits the counter from counting down below 0 depicted in Figure 6. OR gates are used in both instances because it only outputs a low for a distinctive case which is when all inputs are 0 [8]. Each decimal has a unique binary value and hence multiple OR gates are cascaded to evaluate all eight binary inputs. Once the specific binary value is reached for both counters the output to the UP pin (Pin 5) remains high. Similar logic is applied for the DOWN pin.

3.3 Results and Evaluation

The current through the display without resistors was simulated to be 1.11kA and the current with resistors was simulated to be 9.73mA thus the current is limited to a mA range.

Table 2: Table showing results obtained from simulations and measured from circuit.

Component Measured	Simulated	Measured
U9A NOT Gate (output) Before 0	5V	4.76V
U9A NOT Gate (output) After 0	0V	0.14V
U16A OR Gate (output) Before 82	0V	0.19V
U16A OR Gate (output) After 82	5V	4.75V

The designed circuit yields the expected results and is thus successful.

4. INTERNAL LIGHTS: JONATHAN TAYLOR(1665909)

The indoor lighting works in three stages; the first stage is always on as long as there are people in the pool area (first condition), the second stage is on provided the first condition and the light is below a certain level and the third stage (competition) is on provided the first condition and the switch is set to on.

4.1. Design Specifications

Stage one is powered directly from the OR gate output from the outdoor circuit. A phototransistor checks the lights levels to activate the stage two LED and a switch is used to activate the stage three LED. The latter two stages use the amplified 9V input from the non-inverting amplifier.

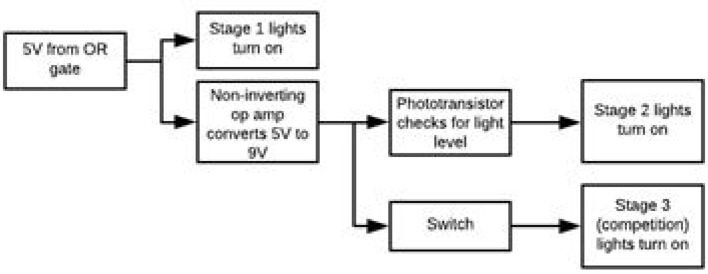

Figure 7: Block Diagram of Indoor Lighting System

4.2. Design

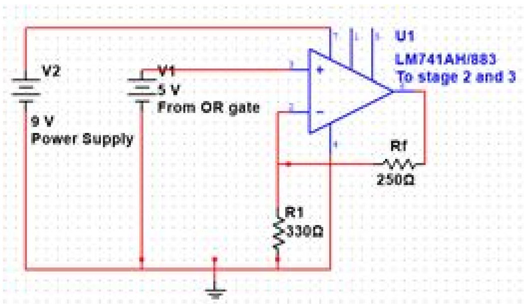

Figure 8: Non-inverting op-amp circuit

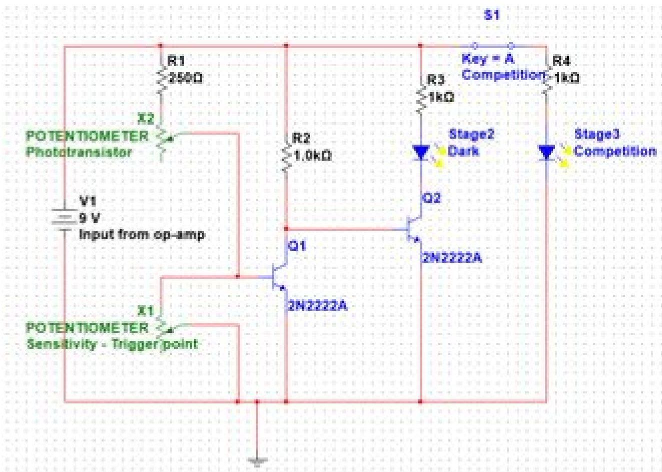

Figure 9: Stage 2 and stage 3 circuit

Figure 8 is a simple non-inverting op-amp circuit to convert the 5V input to 9V as required by the stage 2 and 3 circuit. Figure 9 is a high gain transistor circuit [10] as seen by the two transistors needed to power the stage 2 LED. This was motivated by the design of photo-Darlington transistors [11]. Additionally, the use of the phototransistor in a voltage divider configuration proved useful as a way to manipulate its light-dependant resistance [9].

4.3. Results

Table 3: Important values recorded in the Indoor Lighting System

Component-measurement (units)	Calculated		Simulated		Measured	
	Light	Dark	Light	Dark	Light	Dark
Phototransistor – resistance (kΩ)	0	10	0	10	30	40

Stage 2 Yellow LED – current (mA)	0	19,53	0,00157	16,82	0,002	17,11
Stage 3 Yellow LED – current (mA)	0	20,00	0	21,20	0	19,53
Potentiometer X1 – resistance (kΩ)	<4,70	≥4,70	<4,70	≥4,70	<1,54	≥1,54
Non-inverting op-amp – voltage (V)	Input	Output	Input	Output	Input	Output
	5	8,79	5	7,57	4,38	7,70

4.4. Design trade-offs

The phase three LED is not placed in series with the phase two LED as it affects the voltage going through both and yields unsatisfactory brightness when this design is tested. The phase three LED is thus placed in parallel with the phase two LED circuit. This yields a higher brightness, but meant the stage three lighting was not affected by the ambient brightness level like the phase two LED.

4.5. Design evaluation

This design is a success as it behaved practically how it is designed to. The light level at which the phototransistor would trigger the LEDs to be on could be adjusted, a useful feature allowing the user to change this trigger point depending on ambient light conditions. However, the circuit could be improved by possibly using schmitt triggers to negate any possible false switching of the LEDs if the input voltage is noisy.

5. EXTERNAL LIGHTS: BLAKE DENHAM(1714988)

5.1. Design

The outdoor lighting subsystem is broken down in to two parts, as the subsystem required the use of two sensors. The two parts are security lights and parking lot lights. Dark conditions are defined by dark blue filter paper being placed on the light sensors.

5.1.1. Security lights

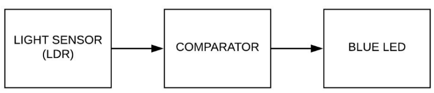

Figure 10: Block diagram of the subsystem design

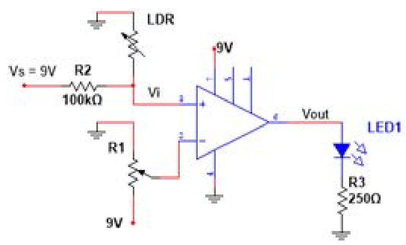

Figure 11: Security lights circuit.

The first part is the security lights, which come on only when light levels are low. The sensor used in the security was a light dependent resistor (LDR). The LDR in the circuit helps in creating an input signal for the non-inverting pin of the comparator, where it is compared to a reference voltage governed by a potentiometer at the inverting pin of the comparator. This allows for an adjustable threshold and therefore an easier way to make the lighting system work when ambient lighting changes. The output of the comparator will then either turn on or off the blue LED. The calculated results were calculated using the formula $V_+ = 9R_{LDR}/(R_{LDR} + 100k)$, $R_{LDR} = 9k\Omega$ when light[13] and $R_{LDR} = 1M\Omega$ when dark[13]. The difference in the measured and calculated results is due to the filter paper not creating complete darkness, therefore R_{LDR} does not equal 1MΩ. By using the measured results, the reference voltage was chosen to be 2.75V, as it is suitable for switching when the paper is put on or taken off the sensor.

5.1.2. Parking lot lights

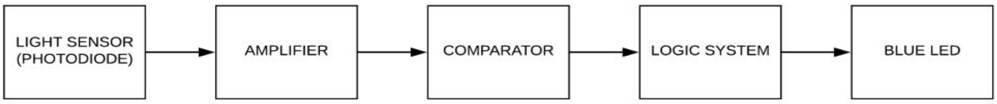

Figure 12: Block diagram for parking lot lights

The second stage is the parking lot lights. These lights must turn on when there are cars in the parking lot and when the light levels are low. The sensor for the parking lot lights is a silicon PIN photodiode. Since there was no system which managed how many cars there were in the parking lot, it is assumed that if the number of people in the bathing load is greater than zero, then the parking lot has cars inside.

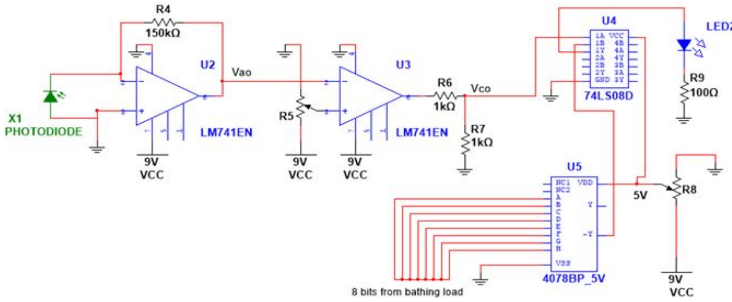

Figure 13: Parking lot lighting schematic

The photodiode generates a reverse current depending on the light shining on it. The range of the current is 2nA to 50µA (dark to light)[15]. This is current is used to generate a signal linearly proportional to R_4 ($Vao = -I_{PHOTODIODE}R_4$). This signal is then compared in an inverting comparator against a reference voltage of 4.7V. The output of the comparator then gets halved in order to create a logic 1 when on and a logic 0 when off for the 74LS08 AND gate[14]. 4078BP is a NOR/OR gate[12]. The OR output of the 8 bits from the bathing load will indicate if there are cars or not. Then the result of Vco and the OR gate are used to switch on or off a the lights.

5.2. Testing Results

Table 4: voltage readings at important points

Variable (unit)	Calculated		Simulated		Measured	
	Light	**Dark**	**Light**	**Dark**	**Light**	**Dark**
V_i (V)	0.74	8.18	0.81	7.61	0.95	6.75
V_{ao} (V)	7.5	0.0	7.52	0.97	5.9	1.2

V_{co} (V)	0.0	4.0	0.4	3.74	0.6	4.1

5.3. Evaluation, trade offs and recommendations

The subsystem worked correctly, however not optimally. To improve the system Schmitt triggers would have been more effective than comparators, and would have made transitions between on and off much smoother. The assumption that people in the bathing load means that there are cars in the parking lot is big, for improvements a parking manager subsystem to link to the lighting would improve the system. From the results, it is clear there is a difference between the calculated and the actual measurements. This is probably due to the fact that blue filter paper does not cause pure darkness, however did provide insight on to what the thresholds for the comparators should be. The simulated results were close to the calculated results except for V_{-sat} from the comparators. The simulations showed that the comparator outputs would not work as logic inputs.

Potentiometers were used for the reference voltages as it makes it the modifiable, however changes on the potentiometer can disable the functionality of the circuit. Ideally a replacement of the potentiometer with appropriate resistors to fix the reference voltage, once a suitable reference voltage was found.

6. TEMPERATURE CONTROL: SUSANA DE ABREU (1640163)

The temperature system is responsible for maintaining a comfortable temperature within the indoor pool area. The ideal temperatures are between 26-29° Celsius. The lower range of temperatures are maintained during winter to ensure that the patrons within the pool do not experience a dramatic temperature change when exiting the pool. The opposite is true for summer as the higher range of temperatures are maintained. In order to maintain the temperature between the given ranges; both a DC fan and heating mechanism were utilized. The heating mechanism was represented by a red LED. When the temperature is within the stated ranges both the LED and fan are off, when the temperature is above the range the fan automatically switches on in order to cool the surroundings and reach the temperature equilibrium that is within the given range. When the temperature is below the range the LED switches on in order to signify the increasing of temperature and switches off once the temperature is within the stated range.

6.1 Design specification and implementation

The electronic system that regulates the temperature, is made up of 7 main components, mainly the temperature sensors LM35 [16], operational amplifier UA741, comparators, an LED, a BJT (base junction transistor), relay 35M0483 [17] and the DC fan. This can be seen in figure 14.

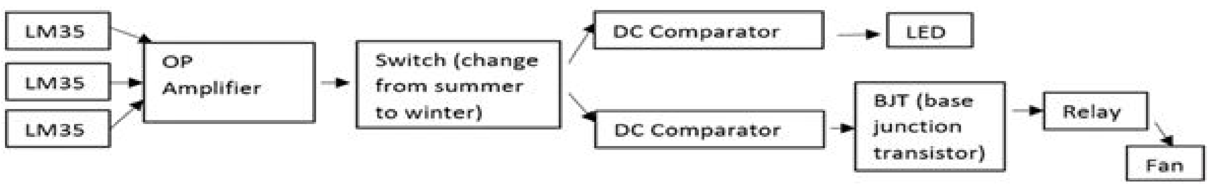

Figure 14: Block diagram presenting temperature sub-system.

The 3 LM35's represented in figure 14 were averaged so that the output voltages of the sensors were not added together but rather an average obtained. This can be seen more clearly in figure 15. The voltage supplied to the circuit was +9V and -9V. The voltage output of the sensors increased with 10mV per ° C and it was observed that if a small interference occurred these values could dramatically change. The voltage was thus amplified to decrease the chance of error that may be caused by the tolerances of the sensors, or the resistor values not being completely accurate. Comparators were thus efficient as a bigger range could be made between the switching point and reference voltage. A switch was incorporated that had a slight resistance to mimic the changes between summer and winter. The comparators were constructed by calculating the switching points, namely 2.07V for the LED and 2.33V for the fan. The comparators used these switching points as the reference voltage. If the temperature increased to 30 °C the voltage out of the sensor would be 0.3V which was amplified to 2.4V by using a gain of 8. Due to the LED comparator being inverted the LED would not switch on but the fan would turn on. The fan is only activated if it has sufficient power, meaning sufficient voltage and current were needed. The fan operated on 5V and a power rating of 0.9 Watts. A comparator alone was not sufficient, a BJT was introduced to increase the current, and a relay [18] to amplify the voltage. The differences in the current and voltage before and after the BJT and relay can clearly be seen in figure 15.

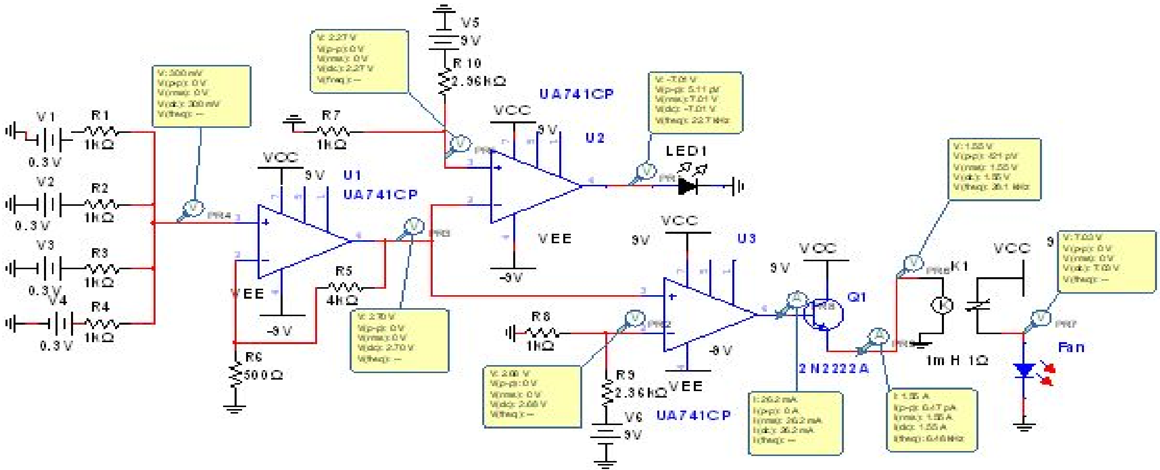

Figure 15: Circuit diagram of full temperature sub-system

6.2 Results

Table 5: Comparison of calculated, simulated and measured results in the temperature sub-system.

Results	Calculated				Simulated				Measured			
	at 25°C		at 30°C		at 25°C		at 30°C		at 25°C		at 30°C	
	LED	Fan	LED	Fan	LED	Fan	LED	Fan	LED	Fan	LED	Fan
Temperature sensor voltage (V)	0.25	0.25	0.3	0.3	0.25	0.25	0.3	0.3	0.257	0.257	0.295	0.295
Amplified Voltage (V)	2	2	2.4	2.4	2.25	2.25	2.7	2.7	2.17	2.17	2.49	2.49
Reference Voltage (V)	2.07	2.33	2.07	2.33	2.27	2.68	2.27	2.68	2.29	2.45	2.29	2.45
Resultant comparator Voltage (V)	>0	<0	<0	>0	>0	<0	<0	>0	>0	<0	<0	>0
Outcome	On	Off	Off	On	On	Off	Off	On	On	Off	Off	On

6.3 Evaluation, Trade-offs and Recommendations

From table 5 it is evident that the circuit design was successful and the calculated, simulated and measured values differed by approximately 12% which is fairly accurate. This could be due to slight inaccuracies in resistor values or the tolerances within components used. Comparators could in future be a trade-off and rather be replaced with Schmitt triggers as less interference would occur. It is recommended that resistors be replaced with precise variable resistors to improve the accuracy of the calculations.

7. HUMIDITY CONTROL: DANIEL TEIXEIRA (1616667)

7.1. Relative Humidity

The specifications for the relative humidity (RH) that are given to control the humidity, are as follows. 50%RH is the stable region for humidity during winter whereas 60%RH is the stable region in summer. As understood if the relative humidity rises above or drops below the stable relative humidity for summer or winter, the indoor pool environment will be impacted negatively. The circuit is required to maintain the humidity levels during summer and winter.

7.2. The Humidity Sensor: How it works

The HCZ-H8A/B humidity sensor works based off of it's impedance. In this case of it's impedance, the sensor refers to its resistivity, which is the amount of resistance or the amount of conductivity. The sensors main principle depends on how much water content there is for conductivity on the non-metallic conductors found on the humidity sensor [19].

7.3. Basic Design

Figure 16 and Figure 17 below describe and layout how the circuit is put together so that humidity in the indoor pool can be controlled and not impact the indoor pool environment negatively.

Figure 16: Block Diagram describing circuit's main components for functionality

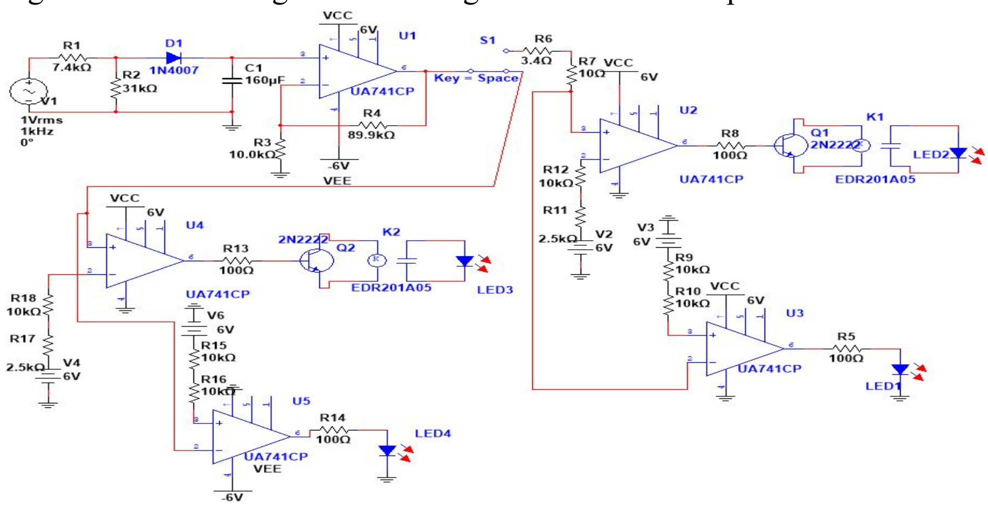

Figure 17: The Schematic of the Humidity Control Circuit

Note that 6V will be supplied by the DC power supply, which is connected to the reference voltages found at the comparators for the conditional checks that consider whether or not the control systems switch on.

7.4. Logic Used for the Working Circuit

Before the humidity control operations are set to work, the input conditions of the input circuit are designed. There is an increase in voltage during winter, whereas in summer there is a decrease in voltage. Two output circuits are designed for summer and winter, implying that the voltage for winter can be dropped to meet the same conditions as summer. Therefore the initial conditions for summer are used as the default non-operating conditions. Refer to figure 16 and continue.

From the signal generator (AC input), there is 1kHz and 1Vrms plugged into the circuit. During winter the output voltage (just before the switch) of the input circuit is calculated to be 5.9V when it is stable whereas in summer the stable output voltage of the input circuit is 4.4V. The output voltage of the input circuit during winter is dropped to 4.4V using a voltage divider before the winter output circuit. Now both seasons are able to operate with the same operating conditions. This is taken as the default non-operating conditions.

Moving on to the output circuits (after the switch), the comparators are set up as follows. The two output circuits consist of an inverting and a non-inverting comparator. At the comparators, when there is an increase in impedance, the comparator compares the output voltage of input circuit to the DC power supply [20]. Since there is an decrease in impedance, there is a increase in humidity and therefore the relay switches on for the operation of the motor as well as the LED which represents the fan during summer [21]. The winter circuit follows the same procedure but the voltage is dropped to match summer's conditions before the comparators for the same operating conditions.

7.5. Simulations and Results

Below is the set of summarised results used for the fully functioning circuit. The impedance for the different humidities were retrieved from the HCZ-H8A/B specification sheet.

Table 6: Represents the different outputs as to the circuits operating conditions work.

Input Voltage (V)	RH (%)	Impedance of Humidity Sensor (kΩ)	Output Voltage of Input Circuit (V)	Non-Inverting Comparator (V)	Load is on or off	Inverting Comparator (V)	Load is on or off
1.41	45	160	C - 6.5, S - 6.6, M - 6.49	C - 4.9, S - 4.78, M - 4.99	on	C - 4.9, S - 4.78, M - 4.99	on
1.41	50	87	C - 5.9, S - 5.4, M - 5.87	C - 4.4, S - 4.333, M - 4.37	off	C - 4.4, S - 4.333, M - 4.37	off
1.41	55	49	C - 5.3, S - 5.12, M - 5.22	C - 5.3/4.0, S - 5.12/3.87, M - 5.22/3.97	on/off	C - 5.3/4.0, S - 5.12/3.87, M - 5.22/3.97	on/on
1.41	60	31	C - 4.4, S - 4.36, M - 4.35	C - 4.4, S - 4.36, M - 4.35	off	C - 4.4, S - 4.36, M - 4.35	off
1.41	65	19	C - 3.2, S - 3.111, M - 3.15	C - 3.2, S - 3.111, M - 3.15	off	C - 3.2, S - 3.111, M - 3.15	on

Note that at 55% relative humidity the voltage can be either 5.3V during winter and 4.0V during summer, but the voltage of winter is dropped to 4.0V to meet the same conditions for operation. From Table 6: **C - Calculated, S - Simulated, M - Measured**.

7.6. Design Evaluation

The circuit could be simplified and improved by taking out the second output circuit and using the switch to connect directly to a voltage divider that connects to the rest of the output circuit. The other side of the switch connects directly to the same output circuit, where it skips the voltage divider. Doing this simplifies the circuit even more and saves the use and cost of extra components. The results that were calculated differ slightly to the simulated results as well as the measured results. It is clear to say the values are fairly close and therefore are fairly reasonable to use in this design. Also note that majority of the results were assumed based on engineering hypothesis and theory as to how impedance changes and its relationship with impedance.

8. CONCLUSION

A fully functioning indoor climate system was presented in this report. the complete system was built with each sub-system having simulated results that slightly differed from the measured results. this is due to the simulation running with ideal conditions whereas when measuring values, components used are not completely accurate and have a percentage of error. Overall the indoor pool climate system worked and recommendations have been made regarding each sub-system for future improvements.

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