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Application of Data Logger for Monitoring Indoor and Outdoor Temperature of Buildings: A Review

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Abstract-
A great deal of importance is being placed on the building energy management system all across the globe. A particular emphasis is being placed on methods to monitor building performance, the cost of electricity consumption as well as in other cases, the carbon emissions. This paper considers a critical examination of the various works carried out regarding building monitoring instrumentation multiple applications of a data logger. Furthermore, this paper sheds more light on developing a simple data logger to monitor indoor and outdoor temperature.

Key words: Energy management, instrumentation, building monitoring, data logger

1. Introduction
There is a significant advancement in the use of sensors as brought about the need to incorporate the various intelligent system in buildings [1]. One parameter stands out of the rest when measuring the indoor environment qualities, and that is temperature. Measuring temperature seeks to ensure the comfort of occupants of a building while also at the same time, prevent any fire occurrence [2]. An efficient solution in continuously monitoring temperature will be to develop a data logger. However, traditional data loggers can no longer satisfy a certain degree of accuracy and reliability as there usually feature analogue devices like thermometers. Therefore, the creation of PC based data logging [3] systems has established the advent of micro-controllers, which has increased to a certain level of efficiency and reliability, this has allowed a whole variety of functions with the integration on a single chip. Temperature monitoring using this instrumentation set-up is very much reliant for all objective requirements. When considering temperature as a parameter, special consideration must be put into the type of sensor to use for the monitoring purpose as every sensor has its difficulty associated with the calibration process. When this happens wrongly, readings gotten may differ from the initial measured temperature. This paper aims to highlight various literature on temperature monitoring and data logging techniques and present a simply developed data logger for temperature monitoring. The system can also transfer data through the RS232 excel.

2. Review of Data Logger Techniques
There have been several works carried out on various data logger techniques and temperature monitoring, below are the literature highlighted in this paper;

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An experiment was performed by [4] for a near-zero energy building. This research was carried out south of Italy, in Benevento, which is very close to the Mediterranean. Here, the house model is also referred to as 'SMART CASE' functioning both as a Laboratory and used to measure other parameters, including the indoor environment quality (including the temperature control). However, [5] in their research came up with a different model comprising two nodes, the sensor nodes, and the Gateway/Coordinator nodes. The sensor nodes featured an ADS1115 16-bit analog to digital converter, an Atmega328P with Xbee communication module, and all designed for low power purposes. These communication modules are usually put to sleep most of the time, reducing the node's power consumption drastically. On the other hand, the gateway nodes feature an S2C Xbee module, an Arduino board, and a Raspberry Pi module, which wirelessly receives sensor data from indoors and from the environment. [6] incorporated instruments in carrying out specific tasks, including; access to monitoring over a long time with changing functionalities coupled with advantageous design techniques. For better efficient measurement, loggers placed across the wall of the building, and readings recorded every thirty minutes. Monthly maintenance was carried out on the loggers as monitoring took place over a long period. The study analysed out for eight roofing strategies. [7] used energy-plus to design the earth-bag prototype for various comparison analysis, for the GPU open studio was employed for this purpose. Still, with its ineffectiveness to create a dome, a polygonal dome was built. Various scenarios tested for the process consisted of 18 temperature sensors with humidity sensors attached with a data acquisition control unit, the indoor and the environment air temperatures were measured. Placed at the centre of the earth-bag were four temperature sensors at different measurable heights of 0.80 meters. Also, monitoring the north surface wall were nine temperature sensors placed at the vertical axis for every 0.40m. The two sensors left were included with the twelve sensors to obtain U-value. Temperature data values were logged every five minutes from the external temperature sensor with the cost of energy consumed through an energy consumption meter.

A set-up by [8] measured temperature achieved through a bi-metallic strip, and the simulation executed with the aid of the energy-plus software. To simulate thermo-physical attributes of the materials had to be obtained, the Hotwire method enabled them to get thermal conductivity through the heat shock of a Kapton probe. Material density is also very essential to carry out numerical simulation measured using a volumenometer. For [9] to accurately ascertain the temperature instrumentation process, the evaluating kit made up of five nodes were used, and then placed in a WirelessHART laboratory. A node is positioned at the door entrance and second close to the laptop's fan. The out-standing three are then 1.5m apart from each other in open space without being placed to a heat source. Incorporating the ReTrofit software by [10] in their research, real-time energy simulation, and optimization software toolbox implemented with Matlab. For proper implementation of the model predictive control strategy, the developed system had the following steps.
The steps carried out were in the following order;

- The building information model analyzed, equipped with the necessary tools to parse weather reports, and the building information model generated in gbXML standard.
- Numerical models can be used to generate and solve configured to solve the model build using the building information model data from the direct building modelling.

- The next step is the problem definition; this sets to define the various parameters for optimization and later represented as a linear state space.

For [11] to measure the indoor environment's different parameters, installed loggers in the multiple rooms attached to temperature sensors and relative humidity. Logger spread across the space carried out measurement hourly. In this study, acquired reading is from the kitchen area as well as the living room

The research carried out by [12] featured a wave rectifier with a voltage regulator, an IC 7805, and IC 7812, constantly producing 5v to the current. The parameter to be measured is analogue therefore, an analogue to digital converter will have to be employed. The sensor used to measure temperature is LM35 calibrated in ^{o}C with 0.5^{o}C accuracy. The controller section made use of microcontroller AT89S52, a 40 pin device, displaying a liquid crystal display 44780, a 2X16 line display, and data transferred using RS 232 interfaced with the microcontroller through MAX 232. The set-up by [13] featured a wireless sensor network and had the DHT111 and NodeMCU as the main component, which is a requirement of continuous data recording. The DHT111 sensor can measure both the temperature and humidity readings. The open-source IoT platform, Node-MCU, is time-consuming; moreover, it is publicly accessible for anyone to improve. It makes use of a 6v battery. A wireless sensor network ensures the continuous transfer of data for a long time. A modem has a speed of up to 300mbps is used for this purpose. The WSN allows the individual sensor nodes configured at different and various locations. The set-up provides data on climate change and offers a comfort profile pattern for any specific purpose such as residential buildings, laboratories, cinema, etc. A control system developed by [14] explicitly dedicated to energy management employed a flexible research platform (FRP). The temperature of the room set-point planned has the metasys system assigned all other parameters. The primary sensors deployed in the heat, ventilation, and air conditioning unit and the thermal zones were the temperature/humidity sensors. Sensors used are calibrated. The measurements include; temperature set-points, flow rates, and the energy consumption of the components present in the building. The data reading schedule is in 1min, 15mins, and 60mins intervals. A weather station was installed above the flexible research platform to measure the following components: outdoor air temperature, humidity, solar radiation, and wind speed and direction.

Incorporating the air temperature and wall surface temperatures between May and April [15] used the Hobo data logger for this purpose. The calibration aids to record air temperature with further four external probe sensors attached to aid with the surface temperature readings and can measure temperature range from -20 to +70^{o}C. The data loggers were placed away from any form of radiation by shading during the process. Animals kept in an aquarium employed raspberry pi to control data logger measurement. An infrared barrier with the ability to detect the animals' movement at any given time carried out by [16] in regards to the health sector, a thermo-data logger was used for continuously measuring changes in the temperature of the rectum. The thermometer with power from a battery and is capable of storing up 2048 data sets. Every five minutes had a data entry. The system is capable of saving temperature records for seven days, and the battery could last for four years. The ambient temperature was measured by placing another data logger in the body's ankle [17]. [18] developed a system whereby a domestic heat pump was installed in all cubicles to ascertain hot and cold tendencies. A device built with a function of registering the inner surface temperature and electrical energy consumed by the heat, ventilation, and air conditioning system. [19] Incorporated a SUNA with a data logger. It was able to use the system for water quality monitoring with its sensor. A Tr-2050 data logger deployed with the SUNA. This data logger begins to work at depths exceeding 1200 calibrated up to ±0.002^{o}C. A data logger has an Rf link constituting 2mb of RAM with a digital data processor and controller and employed in the health sector. It was able to examine the stress existing in dental prosthesis. To endeavor that every relevant data was retrieved, the digital processing unit implanted on the board. The device incorporates 132 kHz for arbitration to ensure there is appropriate communication command transmitted to the Logger [20]. In a bid to cut the high cost of data logger by manufacturers, conscious efforts to develop cheaper data loggers using the Arduino microcontroller, which is very suitable for measuring temperature. The instrumentation featured Arduino pro mini with Atmega 328P and a DS 3234 to control time. To measure temperature, the system used a 10k PT103J2 [21]. [22] developed a temperature monitoring system to monitor the temperature across the skin and the feet. The system is made up of two parts, while one part is involved with measuring the voltage drop; the second part deals with transferring the measured data to a PC through the RFID interface.

The specifications of the data logger by [23] featured DS18B20 sensors that measured air temperature and globe temperature, sensirion SHT21 for the relative humidity, Broadcom-APD5 for light intensity, a condenser microphone and preamplifier for sound level and frequency, wind sensors rev p. for the air velocity; SHARP, GP271010AU0F for air particles; COZIR, GC0010 FOR CO_2 concentration. While [24] used sterile guinea pigs as test subjects and had data logger implanted in their abdomen, which occurred along the midline. The abdominal temperature of the guinea pig was recorded. All Logger used a non-replaceable battery, EEPROM memory chip, and a thermistor. The temperature was recorded every 5 minutes with a possible record of up to 112 days of uninterrupted recording. A further study by [25] featured a data logger characterized by a microprocessor, an ADC, a DS 3232 serving as real-time clock transferring data between the Logger and the computer system, done via the RS 232 with the WINTEMP software. The memory holds up to 64,800 measurements. A comparison test was carried out here by [26] through the use of the robonerite temperature data logger as against other temperature data logger types. These types of Robo data loggers have DS1922L I-buttons, which removes the option of dismantling. The data loggers are made using nerite shells. The food processing industry [27] was able to collect data at a specific time interval, which is logged onto a computer system. Wireless data loggers are fits with thermistors for recording how much heat penetrates through food. The instrumentation process made used by [28] has the VLC and Hadoop, which involved monitoring and collection. It is charged with distributing storage of numerous temperature values. A thousand records are managed per minute, which sums up 1.44 million in a day.

The monitoring system proposed by [29] had the Atmega 328P as the monitoring base; the DHT11 sensor measures the temperature readings, further analysed by the data logger. The DS1302 real-time clock enabled all data records in the exact time of entry. A low power model was developed to maximize battery life. For a full thermal absorption, the sensor enclosure was painted black and wire coatings insulated adequately with PVC. Attached were two extra outputs to serve in any situation of failure. Fifty-three data loggers were utilized by [30] with an additional ten in the latter part of the study to enable cold and hot tests. For four days, each Logger was able to log data for five minutes. One sensor was placed inside a Stevenson screen, and another two put on the hook of a radiation shield. The average values of all the sensors were then calculated and compared. Setting up the instrumentation process at the University of Newcastle [31] develops a model to compare Walleye systems' thermal performance. A Data-taker DT600n was used for recording various parameters, including temperature. In employing Hobo-12 Logger, sensors were fixed at wall partitions to enable a thorough study of the indoor and outdoor temperature data [32]. Making use of a sensor network, which is managed by a micro-controller, made use of sensing nodes enable to record the indoor and outdoor temperature on the considered wall [33]. The sensor node spreads with a data logger through an RS485 protocol, and collected data is checked and managed by a web application that continuously monitors each parameter's states. The measured parameters monitored with a sampling time of 1s after which data collected are sent by the data logger to the webserver in real-time through GSM/GPRS connection. The web application interfaced with a monitoring system with a data profile of outdoor temperature inner temperature and wall inclination.

An Eltel 40l data logger made use of a monitoring process by collecting data over five minutes. Successfully setting up the process, a heat flux meter attached with a thermistor was incorporated. Consciously restricting external factors like radiation, the removal of the sensor from having contact with the radiation. Thermistors were used in this study to obtain temperature data, and this was for just a single wall [34]. The instrumentation by [35] from this study puts out a data logger instrumentation with a micro-controller and an analogue to digital converter that measures temperature while there is a digital to analogue converter that helps to prevent heat. Reconfiguration can be done through a USB. Another series of temperature readings begins when the ball's temperature at normalcy and the environment is at equilibrium. Two data loggers (HOBO U12-012) were used to measure the dry-bulb temperature at 10 minutes interval. This instrumentation set-up was out of the reach of direct sunlight, which meant frequent monitoring by the user. In other to ascertain external parameters, the HOBO loggers were placed on the fence [36]. [37] used two data-loggers to monitor 141 readings directly. The temperature reading executed every thirty minutes. The collected data enables us to find the mean indoor temperature during the occupancy of buildings, while four data loggers are employed to measure outdoor temperature. The Logger has ±0.5^{o}C of accuracy for temperature.

[38] incorporates a means of data collection with the use of a CR1000 data logger. Data logging is carried out automatically, and flash memory cards stores data that is transferred to a computer system every week, and this then backed up on a server. Data acquired is usually through the Campbell Scientific Nb115 over a local network. Typical modifications were made by [39] in this instrumentation set-up; an onset HOBO pendant was modified to stream temperature, intermittency, and Conducting Logger; when this happened, the light sensor was re-engineered for electrical conductivity logging while the temperature logging was maintained. It was able to store 28,000 temperature values. The STIC instrumentation made use of the running standard HOBOware Pu software. An observation carried out by [40], from

the instrumentation set-up, highlighted that ±0.25^{o}C of accuracy and -4^{o} to 37^{o}C is the temperature range which all represent the minimum standards.

In a set-up by [41], they observed the use of wireless sensor networks to build temperature monitoring systems that could be self-organized and distributed to monitor the temperature in real-time to prevent hazards from occurring in an environment like fire. The ZigBee communication protocol was used here with the IC-CC2500 and 2.4GHz(ISM) radio frequency module. The sensor node can detect any slight differences in the local temperature and transfer data for the CPU, which happens over a continuous loop made possible by the HyperTerminal. A Delta-log 10.V.0.1.5.28 with regards to standard regulations is used to observe the indoor microclimate. Logging occurs every five minutes exported with the help of the software Deltalog 10 onto an excel file. Parameters measured are the globe temperature, natural ventilation, and the ambient temperature [42]. [43] developed a monitoring system made up of a PC, workstation, and a system for communication. It consists of a pyranometer and a temperature sensor for gathering weather reports and later transferred to a PC through a serial connection.

3. Hardware Description

The circuitry of the temperature data logger for the experimental set-up has sub-categories into the following sections

(a) **Power Supply Section**: This section equipped with a wave rectifier with the IC 7805 used to regulate the voltage, whereas the presence of the IC 7812 keeps a constant 5V voltage in the circuit.
(b) **Controller Section**: The micro-controller, which is the PIC18F876, features a five-channel of 10-bit Analogue to Digital converter, being a low power micro-computer with 8K of flash programmable and 256 erasable read-only memory (EPROM).
(c) **Display Section**: temperature data measured at every given will have to be displayed. The LM016L is used, which is also a 16-character X 2-line display.
(d) **Hardware Controlling**: the DS3231 module is a real-time clock that maintains accurate timekeeping of measured temperature data even when the device's main power is interrupted.
(e) **Data Transfer**: the temperature data measured and recorded on the data logger will log onto Microsoft excel, and this will be achieved by transferring data to RS 232, which is interfaced with the PIC18F876 through MAX 232.

3.1 Design Description

The schematic diagram representation in figure 1 features the various materials used to develop the data logger. These comprised of two LM35 temperature sensors, which typically are used to measure the indoor and outdoor temperature values, which in most cases, is used to test out the effectiveness of the building thermal insulation materials being incorporated in a particular building. The sensor placed inside the building is used to measure the thermal comfort level achieved with the thermal insulation material. The LM35 temperature sensors here happen to give more accurate values against using a thermistor output. The micro-controller used here is the PIC18F878, with its flash memory utilization as the storage unit. The micro-controller is programmed to measure temperature readings every five minutes. The

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DS3232 is a real-time clock that gives an accurate record of various times for temperature data measured during the observation stage. The values displayed on a 20 X 4 LCD screen allow for the date, time, and indoor and outdoor temperature values measured to reveal per time. For accuracy against other traditional forms of data logging, the temperature readings will automatically be transferred to an excel file on the computer system through the RS 232.

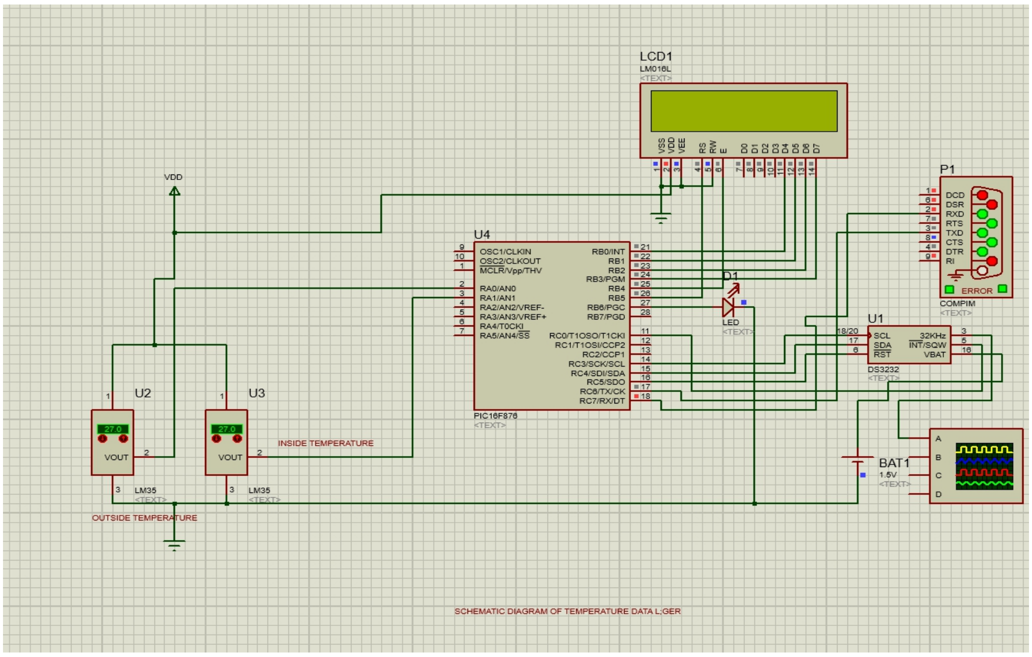

Figure 1. Embedded Control Hardware Circuit – Schematic Diagram

A house model developed with Auto-desk fusion 360 software shown in figure 2. It features a 60cm length by 60cm breadth by 50cm height in dimensions. The house model has a door in the front wing to enable airflow convection in and out of the house. The material used in this model is aluminium; this allows maximum absorption of heat for transmission.

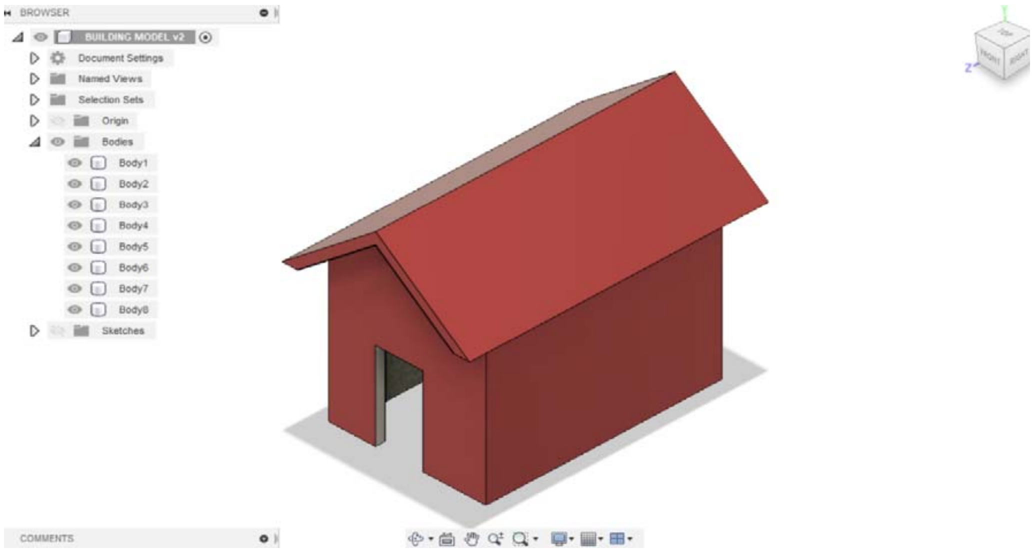

Figure 2. Aluminium house model.

Figure 3 below shows how the polyurethane is used to pad the house model, and polyurethane is the thermal insulation material. The polyurethane used insulates the wall and reduces the heat between the walls. It is also placed in a structure of the roof to reduce to a considerable extent the heat coming into the house model; this is because the roof is the closest contact to solar radiation.

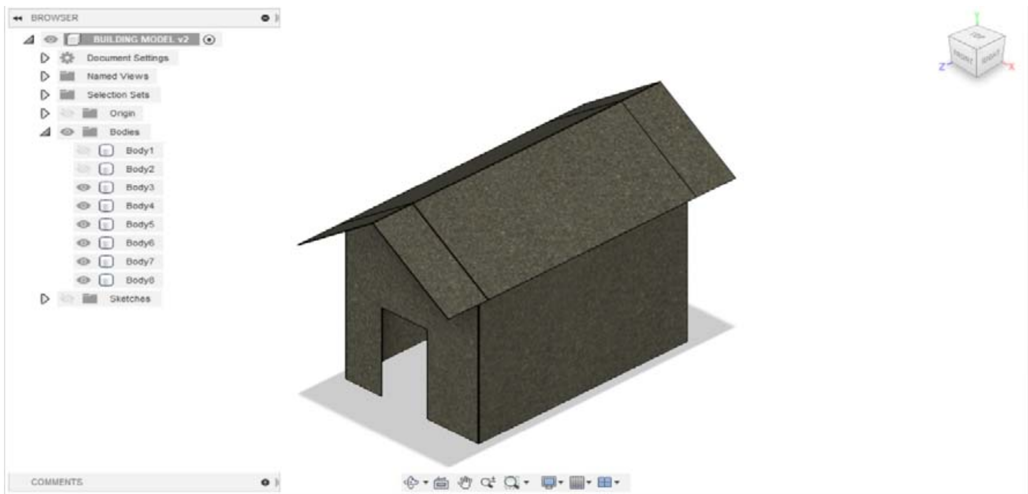

Fig. 3 The polyurethane foam used to pad house model.

Conclusion

A data logger's importance in measuring and recording various parameters cannot be overemphasized as it helps serve in different capacities, from accuracy to reliability and timely manner, materials investigated as in the case of the polyurethane foam padded around the house model. The various literature reviewed in this paper has helped to further pin-point how data loggers serve in building temperature instrumentation. More emphasis should, however, on manufacturing more local data loggers from conventional materials; this will invariably serve extra cost and help to incorporate other features better as desired by the user.

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