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ORIGINAL PAPER

Development of an Online Heat Index Measurement System for Thermal Comfort Determination

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Abstract: This paper presents the development of a reliable heat index (HI) measurement system for evaluating the thermal comfort of a particular building or a particular area. The HI is an index that combines air temperature and relative humidity (RH) to determine the human-perceived equivalent temperature. To measure the air temperature and RH, temperature to digital converter and RH to voltage converter is used. HI is calculated online with the help of embedded firmware of the microcontroller. This calculated value is then transferred to the computer through standard RS 232 serial port. The same sensor node is tested with the RS 485 network standard by changing the transceiver of the node. The system is calibrated using four standard saturated binary salt solutions.

Keywords: Relative humidity (RH) and temperature; Heat index; Thermal comfort; Sensor node

1. Introduction

Suitable thermal conditions are the essential requirement of the indoor environment. Under such conditions human desires for thermal comfort are satisfied for better performance. Undesirable environmental condition can lead to occupant dissatisfaction which has an adverse effect on their productivity and performance. In most modern buildings, thermal-comfort is achieved through complex Heating, Ventilation and Air conditioning (HVAC) systems, raising the possibility of the occurrence of thermal-comfort problems during the day-to-day activities of the building [1]. Thermal comfort standards are required to help building designers to make a thermally comfortable indoor climate for the occupants. People have a natural tendency to adapt to changing conditions in their environment. This natural tendency is expressed in the adaptive approach to thermal comfort.

There is no absolute standard of thermal comfort. An internationally accepted definition of thermal comfort, used by American Society of Heating, Refrigerating and Air Conditioning (ASHRAE), is that condition of mind which expresses satisfaction with the thermal environment [2]. Nicol et.al [3] reported that, the adaptive approach and explores some of the recent research bearing upon it. It then suggests ways in which the findings of adaptive thermal comfort can help frame sustainable standards for indoor climate for buildings in the future.

It was in 1956, when Kerka and Humphreys began their studies on local thermal comfort of indoor environment. The main findings in these studies reveal that the intensity of the odour goes down slightly with some increase in atmospheric humidity. It is also obtained that, the intensity of the odour goes down with increasing temperature, in the presence of smoke snuff, for a constant partial vapour pressure [4].

In 1983, Cain et al. studied the impact of temperature and humidity on the perception of air quality. They concluded that the combination of high temperatures (above 25.5 °C) and a relative humidity (RH) above 70 % exacerbate odour problems [5]. In 1989, Berglund and Cain [4] discussed the adaptation of pollutants over time for different humidity. This study concluded that the air acceptability, for different ranges of humidity at 24 °C, is stable during the first hour. It was also concluded that the subjective assessment of air quality was mainly influenced by temperature conditions and RH and, secondly, by the polluted air. The linear effect of acceptance is more influenced by temperature than by RH.

The thermal sensation of people are influenced by four environmental factors (temperature, thermal radiation, humidity and air speed), and two personal factors (activity

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and clothing). This is the ASHRAE standard based on the heat balance model of human body [6]. It is seen that temperature and RH plays an important role in the thermal comfort. So it is necessary to measure the temperature and RH indices which are known as heat index (HI) that can be used to measure the thermal comfort. Thermal comfort measurement is necessary because it explains the thermal sensation of human being in a particular environment. It is very important that people should live in a thermally comfortable environment to avoid physiological problems. Otherwise the workers who are exposed to hot and humid conditions are at risk for heat related illness. This situation is particularly serious when hot weather arrives suddenly early in the season, before workers have had a chance to adapt to warm weather.

In this paper development of a low cost HI measurement system is described. The ambient RH and temperature is measured using RH and temperature sensor. The temperature compensation of the RH sensor and HI calculation is achieved with the help of embedded firmware of the microcontroller. Due to its network capability the node can be used as a smart sensor node with slight modification in the firmware.

2. System Description

The block diagram of the system is shown in the Fig. 1. The temperature is sensed by the sensor temperature to digital converter (TDC) [7, 8] and its digital value is read by the microcontroller (AT89S52) in SPI mode [9]. The analog signal from the humidity sensor [10] is fed to a 12-bit serial A/D converter the reference voltage of which is 4.095 V using a floating gate technology [11]. The A/D converter is interfaced with a microcontroller in SSI mode. The system is calibrated and the digital data is converted to its corresponding temperature and humidity. Then taking these values, HI is calculated and all these values are sent to PC via RS232 serial communication [12, 13]. For convenience a local display (LCD) is also interfaced with the microcontroller for displaying the value of temperature, RH and HI.

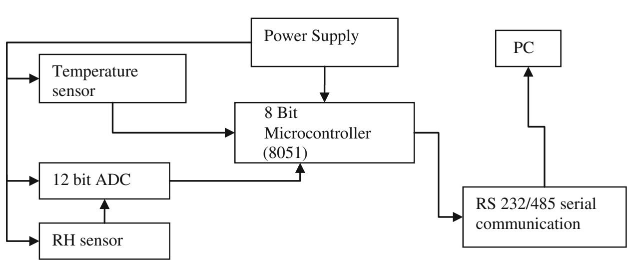

Fig. 1 Block diagram of the complete Hardware

The whole set up is also tested with RS 485 network standard by changing the transceiver of the node [14].

2.1. The Sensor

2.1.1. Sensing of RH

For sensing RH, low power RH to voltage converter is used (Fig. 2) [10]. It is basically a LASER trimmed, thermoset polymer capacitive type sensing element with on chip integrated signal conditioning [15]. The accuracy of the sensor is ±3.5 % at 25 °C with 5 V DC supply. The output voltage (V_{OUT}) and RH can be expressed typically at 25 °C [10] as:

$$RH = \left(\frac{V_{OUT}}{V_{SUPPLY}} - 0.16\right) \times 161.29\,\% \tag{1}$$

2.1.2. Sensing of Temperature

The TMP121 is a 12 bit SPI-compatible temperature sensor which requires no external components for conditioning (Fig. 3). The TMP121 is capable of measuring temperatures within 2 °C of accuracy over a temperature range of −40 to +125 °C [7, 8]. The digital data corresponding to the temperature can be read directly.

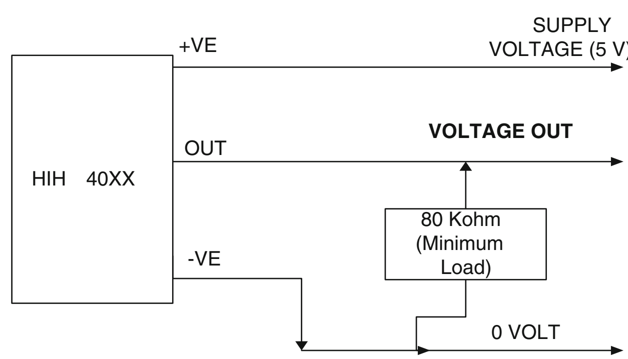

Fig. 2 Typical application circuit of humidity sensor

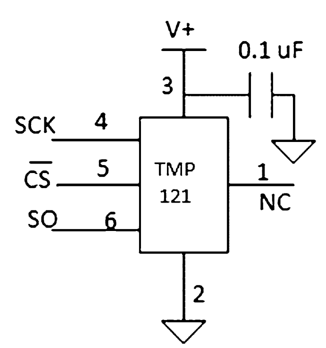

Fig. 3 Typical application circuit of temperature sensor

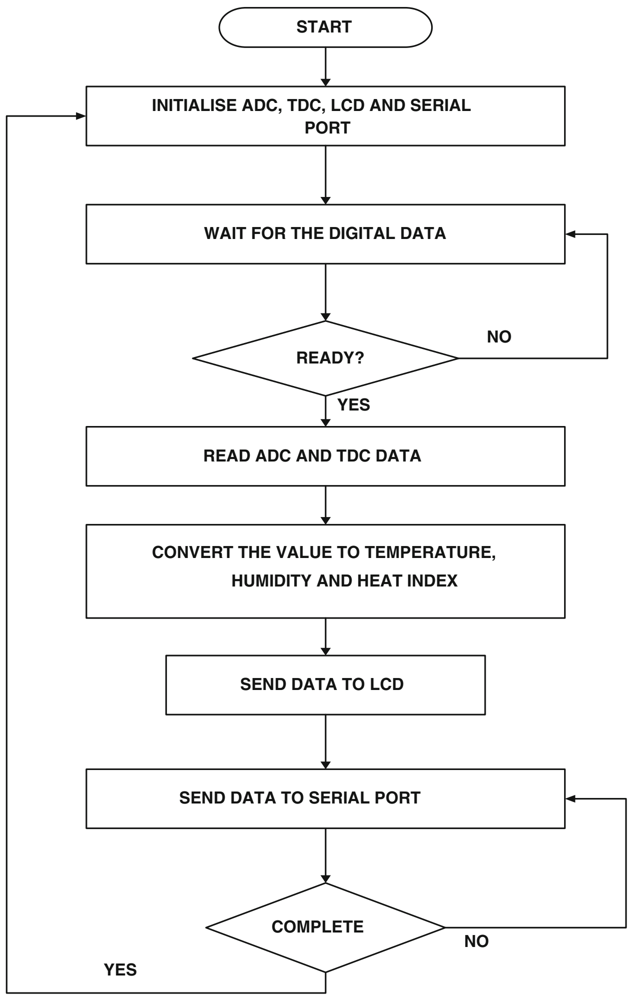

Fig. 4 Flow chart of the firmware

2.2. The Software

The required firmware for data conversion, correction, and transmission to the PC is done with the help of KEIL integrated development environment (IDE). Flowchart of the firmware is shown in Fig. 4. The software required at PC to receive data serially is developed by visual basic. It receives data serially through COM port. The raw digital data is then converted to temperature and humidity.

3. Calibration and Results

3.1. Calibration

The system is calibrated for temperature and RH which is used to calculate the HI. The system is calibrated using four standard saturated binary salt solution at 25 °C. The corresponding RH values for the selected binary salts are shown in Table 1 with uncertainty shown as ±available on

Table 1 The selected binary salts with standard RH values [16]

Sample	Standard RH at 25 °C
S1: potassium hydroxide	8.23 ± 0.72
S2: magnesium nitrate	52.89 ± 0.22
S3: sodium chloride	75.29 ± 0.12
S4: potassium sulphate	97.30 ± 0.45

Humidity Fixed Points of Binary Saturated Aqueous Solutions by Greenspam [16]. The solutions are prepared according to OIML R121 [17]. Distilled water is selected as solvent. The sensing part is inserted in the hygrostat which is a closed vessel containing the hygrostatic solution. The variation of RH is monitored in a PC. When system shows a stable value of RH for 30 min, 100 readings are recorded using on line data acquisition facility of the system. The average value for HI is given in Table 2 by taking the average value for RH and temperature. The standard deviation for temperature, RH and uncertainty of measurement [18–23] for HI of each sample is also given in Table 2. Uncertainty of measurement is estimated using type A evaluations method. For each condition the uncertainty has been estimated from 100 measurements of HI. Table 3 represents the standard HI of binary salt solution at 25 °C controlled room temperature with conversion of °C to °F and vice versa.

3.2. Test Results in Ambient Condition

In the ambient condition the system is tested for 12 h and the data logged in the computer is shown in the graph plotted in Figs. 5, 6 and 7. Figure 5 shows the variation of temperature in the 12 h and Figs. 6 and 7 shows the variation of humidity and HI for the same time. Figure 8 shows a comparison plot of temperature, RH and HI which signifies the importance of HI measurement. It was January 5, 2013 when the data taken in a room of size 15 × 12 square feet. It is a well ventilated room where all windows were open in the west direction at the time of data logging. The longitude and latitude of the room where the data taken is 26°9′10″ north and 91°39′33″ east respectively.

The HI in °F is calculated using the following formulae [24],

$$\begin{aligned} \mathrm{HI} = & -42.379 + 2.0490(T) + 10.143(\mathrm{RH}) \\ & - 0.22476(T)(\mathrm{RH}) - \left(6.8378 \times 10^{-3}\right)\left(T^2\right) \\ & - \left(5.4817 \times 10^{-2}\right)\mathrm{RH}^2 + \left(1.2287 \times 10^{-3}\right)(T)^2\mathrm{RH} \\ & + \left(8.5282 \times 10^{-4}\right)\mathrm{RH}^2(T) - \left(1.99 \times 10^{-6}\right)(T)^2\mathrm{RH}^2 \end{aligned}$$

where HI is the heat index in °F, T is the temperature in °F, RH is the relative humidity in percent form

Table 2 Calibration data and measured HI with uncertainty of measurement

Sample	Standard %RH in 25 °C	RH measured by the system	Temperature in °C	Standard deviation for RH	Standard deviation for temperature	Heat index in °C	Uncertainty of measurement of heat index (±)
S1	8.23 ± 0.72	8.5	25	0.16	0	24.34	0.00096
S2	52.89 ± 0.22	53.14	25	0.15	0	25.93	0.00028
S3	75.29 ± 0.12	75.43	25	0.17	0	25.94	0.00029
S4	97.30 ± 0.45	97.27	25	0.37	0	25.42	0.0013

Table 3 Standard HI of saturated binary salt solution in °F and its converted value in °C

Sample	Temperature of the controlled condition		RH of the saturated binary salt solution (%)	Standard heat index	
	In °C	In °F		In °F	In °C
S1	25	77	8.23 ± 0.72	75.79	24.33
S2	25	77	52.89 ± 0.22	78.67	25.92
S3	25	77	75.29 ± 0.12	78.68	25.93
S4	25	77	97.30 ± 0.45	77.77	25.43

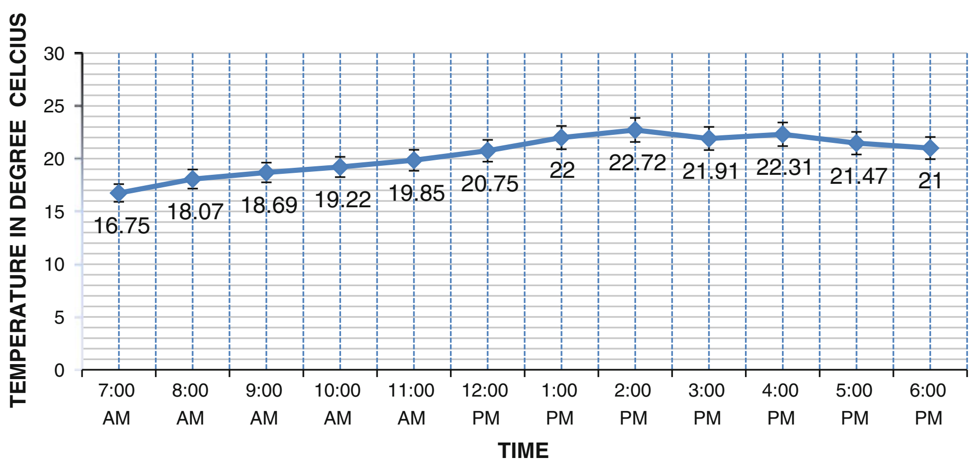

Fig. 5 Temperature variation of a day with *error bar*

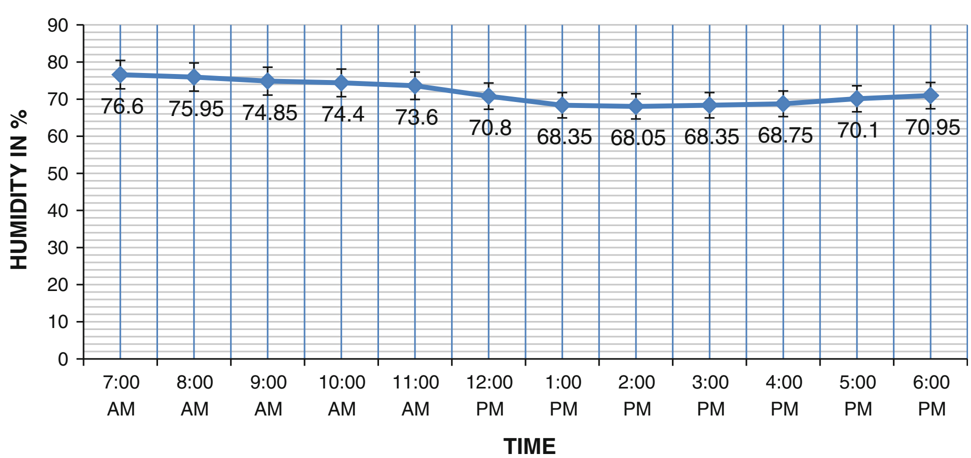

Fig. 6 Humidity variation of a day with *error bar*

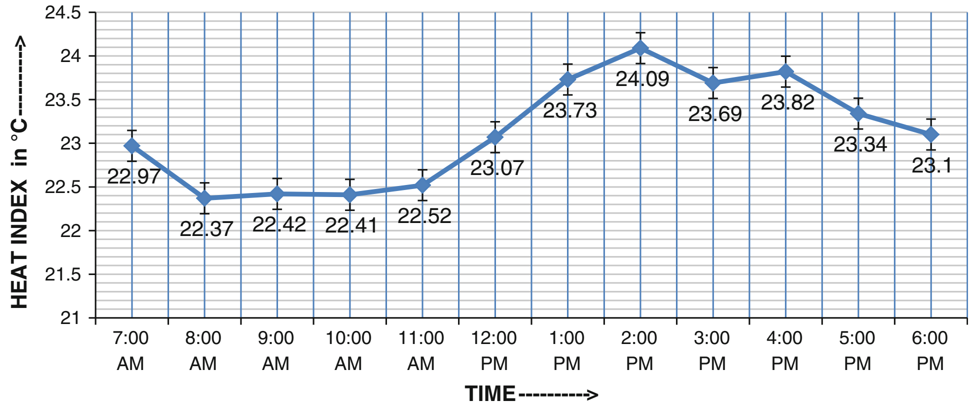

Fig. 7 HI variation of a day *error bar*

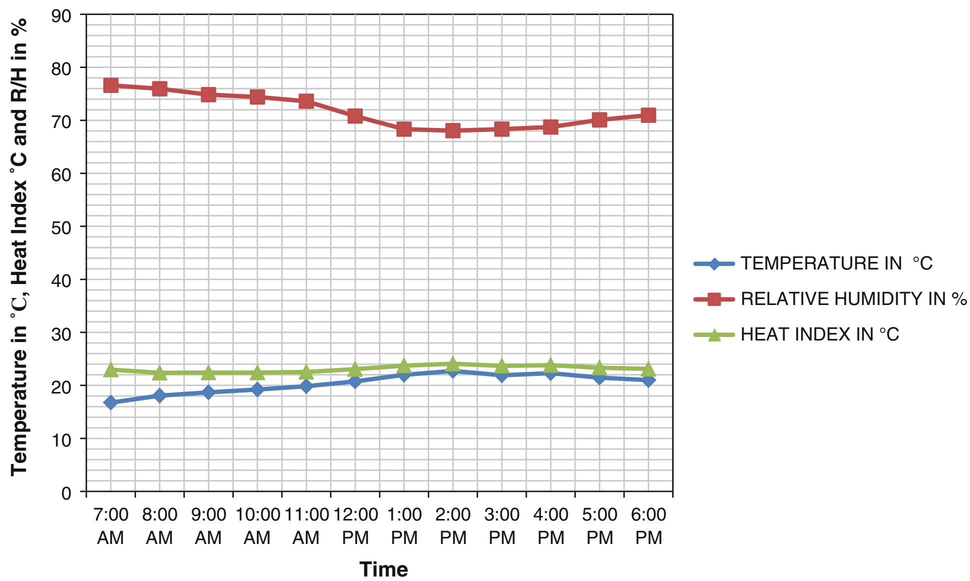

Fig. 8 Comparison plot of temperature, RH and HI

4. Conclusion and Discussion

A HI measurement system is successfully developed and constructed. This system is calibrated for different humidity with the standard saturated binary salt solution. The environmental condition can be changed by changing the humidity as well as temperature. Then the HI will be different (shown in Table 2) which can affect the thermal condition of the place and can disturb the thermal comfort. The system can be transferred to the wireless network which will be very useful. Additionally an EEPROM may be used with the sensor node to store data locally instead of logging data in the HDD of PC [13].

It is advantageous because of its low cost, small hardware setup and ease of installation. This system can be used in a RS 485 network system to get the HI of different places at the same time by changing the transceiver only. The test result shows that the system is not only reliable as a HI indicator but also convenient as temperature and RH indicator. Therefore the system can be used for industry standard application.

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