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# Solar Energy Harvesting in WSN with Development Tool

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**Jiabing Guo**

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<p>Abstract</p> <p>The aim of this thesis was to introduce a solar energy and wsn, as well as to introduce how the solar energy harvesting development tool helps create a perpetually powered wireless sensor network and provides enough power to run a wireless sensor application with no additional batteries.</p> <p>Solar energy is radiant light and heat from the sun. WSN is widely used in modern society. In this project these two areas were combined and it was studied to use the solar energy harvesting in a wireless sensor network with the development tool.</p> <p>As a result of this thesis, the SEH module's solar panel was optimized for operating lights, which provides enough power to run a wireless sensor application with no additional batteries.</p>			
Keywords Solar Energy, WSN, Solar Energy Harvesting Development Tool			
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4 May 2011  
Kuopio, Finland

Jiabin Guo

## Table of Contents

<b>1 Introduction</b> .....	8
<b>2 Introduction to Solar Energy</b> .....	9
2.1 Energy from the Sun .....	9
2.1.1 Energy from the Sun Absorbed .....	9
2.1.2 Yearly Energy Consumption .....	10
2.2 Applications of Solar Technology .....	11
2.2.1 Solar Lighting .....	11
2.2.2 Solar Thermal.....	11
2.3 Generation of Electricity .....	12
2.4 Energy Storage Methods .....	12
2.4.1 Thermal Mass Systems.....	12
2.4.2 Phase Change Materials .....	13
2.4.3 Molten Salts .....	13
2.4.4 Pumped-storage Hydroelectricity.....	13
<b>3 Introduction to Wireless Sensor Network</b> .....	14
3.1 Characteristics of WSN.....	14
3.2 Platforms .....	15
3.2.1 Standards and Specifications.....	15
3.2.2 Hardware .....	15
3.2.3 Software .....	16
4.1 Component of eZ430-RF2500-SEH .....	18
4.2 SEH-01 Description .....	19
4.3 SEH-01 Operating Characteristics .....	20
4.4 SEH-01 Circuit Schematic .....	20
<b>5 Testing of the Project</b> .....	21
5.1 Preparing Software Needed in the Project .....	21
5.2 Preparing SEH-01 .....	21
5.3 Setting up the CCE Project .....	21
5.4 Debugging End Device and Access Point.....	23
<b>6 Results of the Project</b> .....	27
6.1 PC Sensor Monitor Applications .....	27
6.2 Menu Bar .....	28
6.3 Console Window.....	28
6.4 Graph Window .....	29
6.5 Configurations.....	29
<b>7 Testing of Different Conditions</b> .....	30
7.1 Changing the Transmission Duty Cycle.....	30
7.2 Charging the SEH-01 from Sunlight.....	32
7.3 Charging the SEH-01 from Fluorescent lamp .....	34
7.3.1 Testing of Two Different Lamps .....	36
7.4 Changing the range between SEH-01 and Computer.....	36
<b>8 EnerChip Battery</b> .....	38

<b>9 Conclusions</b> .....	41
References.....	42

## Glossary

HVAC	Heating ventilation and Air Conditiong
CSP	Concentrated Solar Power
SSPS	Solnora Solar Power Station
SEGS	Solar Energy Generation System
ASPS	Andasol Solar Power Station
HSL	Hybrid Solar Lighting
WSN	Wireless Sensor Network
IEEE	Institute of Electrical and Electronics Engineers
MAC	Medium Access Controller
MEMS	Microelectromechanical systems
ASIC	Application-specific integrated circuit
ISA	International Society of Automation
SEH-01	Solar Energy Harvesting Module

## **1 Introduction**

The eZ430-Rf2500-SEH is a complete Solar Energy Harvesting development kit to help create a perpetually powered wireless sensor network based on the ultra-low-power MSP430 microcontroller. It could provide enough power to run a wireless sensor application with no additional batteries.

The purpose of this thesis is to introduce a solar energy and wireless sensor network. As well as to introduce how the Solar Energy Harvesting development tool helps create a perpetually powered wireless sensor network and provides enough power to run a wireless sensor application with no additional batteries. It is also presented how the Solar Energy Harvesting development tool works in different conditions.

This thesis consists of eight chapters. Chapter 1 introduces the topic of the thesis. Chapter 2 introduces solar energy. Chapter 3 introduces the wireless sensor network. Chapter 4 gives detailed information about the solar energy harvesting development tool. Chapter 5 and 6 show the process and results of experiments. Chapter 7 displays how the solar energy harvesting development tool creates power in different conditions. Chapter 8 tells about the experiment with the Enerchip Battery.



## 2 Introduction to Solar Energy

Solar energy is radiant light and heat from the sun, which has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation is connected with solar-power. The resources of solar-power are wave power and wind, sun and light, which account for most of the available renewable energy on earth. Only a small amount of the available solar energy is used.

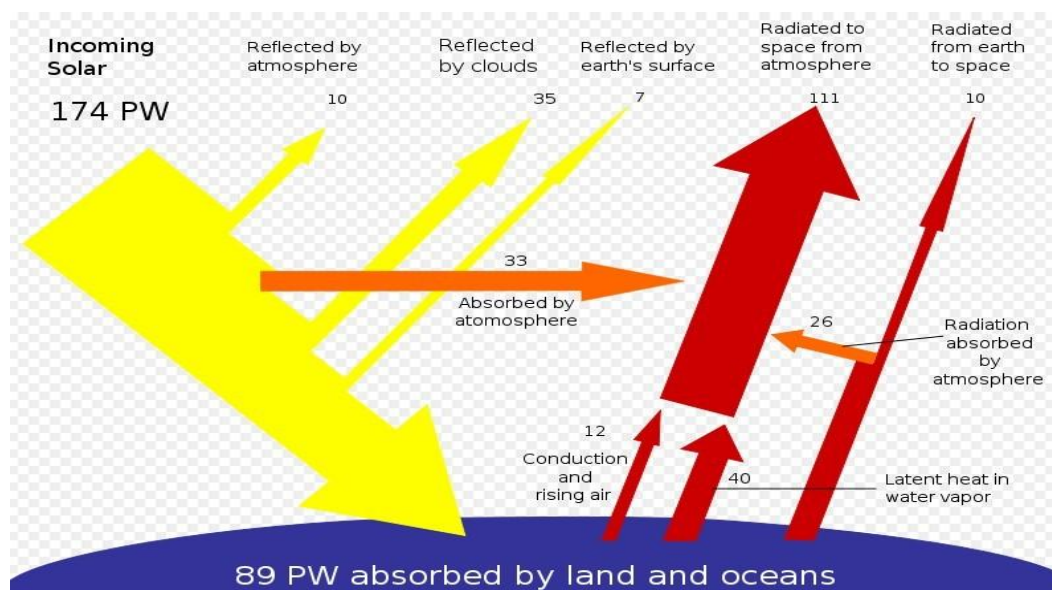
### 2.1 Energy from the Sun

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. [1] Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. [2]

Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. [3] Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. [4] By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived. [5]

#### 2.1.1 Energy from the Sun Absorbed

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. [6] Figure 1 shows that the total energy absorbed by the sun and the operation of the energy. In 2002, this was more energy in one hour than the world used in one year. [7] Photosynthesis captures approximately 3,000 EJ per year in biomass. [8] The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined. [9]



**Figure 1** Energy from the sun absorbed [6]

### 2.1.2 Yearly Energy Consumption

Table 1 presents that solar, wind or biomass would be sufficient to supply all of our energy needs, however, the increased use of biomass has had a negative effect on global warming and dramatically increased food prices by diverting forests and crops into biofuel production. [10] Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available.

**Table 1** Yearly Energy Consumption [10]

Yearly Solar fluxes & Human Energy Consumption	
Solar	3,850,000 EJ <sup>[6]</sup>
Wind	2,250 EJ <sup>[7]</sup>
Biomass	3,000 EJ <sup>[8]</sup>
Primary energy use (2005)	487 EJ <sup>[9]</sup>
Electricity (2005)	56.7 EJ <sup>[10]</sup>

## 2.2 Applications of Solar Technology

Solar technology can be used in many areas. There are a lot of applications in solar technology. For example: solar lighting, solar thermal, electrical generation, agriculture and horticulture, solar chemical and solar vehicles.

### 2.2.1 Solar Lighting

The history of lighting is dominated by the use of natural light. The Romans recognized a right to light as early as in the 6th century and English law echoed these judgments with the Prescription Act of 1832. [11] In the 20th century artificial lighting became the main source of interior illumination but daylighting techniques and hybrid solar lighting solutions are ways to reduce energy consumption. [12]

Daylighting systems collect and distribute sunlight to provide interior illumination. This passive technology directly offsets energy use by replacing artificial lighting, and indirectly offsets non-solar energy use by reducing the need for air-conditioning. [12] Although difficult to quantify, the use of natural lighting also offers physiological and psychological benefits compared to artificial lighting. [12] Daylighting design implies careful selection of window types, sizes and orientation; exterior shading devices may be considered as well. Individual features include sawtooth roofs, clerestory windows, light shelves, skylights and light tubes. They may be incorporated into existing structures, but are most effective when integrated into a solar design package that accounts for factors such as glare, heat flux and time-of-use. When daylighting features are properly implemented they can reduce lighting-related energy requirements by 25%. [13]

Hybrid solar lighting is an active solar method of providing interior illumination. HSL systems collect sunlight using focusing mirrors that track the Sun and use optical fibers to transmit it inside the building to supplement conventional lighting. In single-story applications these systems are able to transmit 50% of the direct sunlight received. [14] Solar lights that charge during the day and light up at dusk are a common sight along walkways.

Although daylight saving time is promoted as a way to use sunlight to save energy, recent research has been limited and reports contradictory results: several studies report savings, but as many suggest no effect or even a net loss, particularly when gasoline consumption is taken into account. Electricity use is greatly affected by geography, climate and economics, making it hard to generalize from single studies. [15]

### 2.2.2 Solar Thermal

Solar thermal is a technology for harnessing solar energy for thermal energy. Solar thermal technologies are useful in the world now. Solar thermal technologies can be

used for so many areas such as: water heating, space heating, and space cooling and process heat generation. [15]

#### 2.2.2.1 Water Treatment

Solar energy may be used in a water stabilisation pond to treat waste water without chemicals or electricity. A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable. [13]

#### 2.2.2.2 Heating

In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ) of the energy used in commercial buildings and nearly 50% (10.1 EJ) of the energy used in residential buildings. [13] Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

### 2.3 Generation of Electricity

Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect. [22]

Commercial CSP plants were first developed in the 1980s, and the 354 MW SEGS CSP installations is the largest solar power plant in the world and are located in the Mojave Desert of California. Other large CSP plants include the Solnova Solar Power Station (150 MW) and the Andasol solar power station (100 MW), both in Spain. The 80 MW Sarnia Photovoltaic Power Plant in Canada, is the world's largest photovoltaic plant. [22]

### 2.4 Energy Storage Methods

Solar energy is not available at night, and energy storage is an important issue because modern energy systems usually assume continuous availability of energy. [16] There are many methods to save the energy such as: Thermal Mass Systems, Phase Change Materials, Molten Salts, Pumped-storage Hydroelectricity and so on.

#### 2.4.1 Thermal Mass Systems

Thermal mass systems can store solar energy in the form of heat at domestically useful temperatures for daily or seasonal durations. Thermal storage systems generally use readily available materials with high specific heat capacities such as

water, earth and stone. Well-designed systems can lower peak demand, shift time-of-use to off-peak hours and reduce overall heating and cooling requirements. [17]

#### 2.4.2 Phase Change Materials

Phase change materials such as paraffin wax and Glauber's salt are another thermal storage media. These materials are inexpensive, readily available, and can deliver domestically useful temperatures (approximately 64 °C). The “Dover House” was the first to use a Glauber's salt heating system, in 1948. [18]

#### 2.4.3 Molten Salts

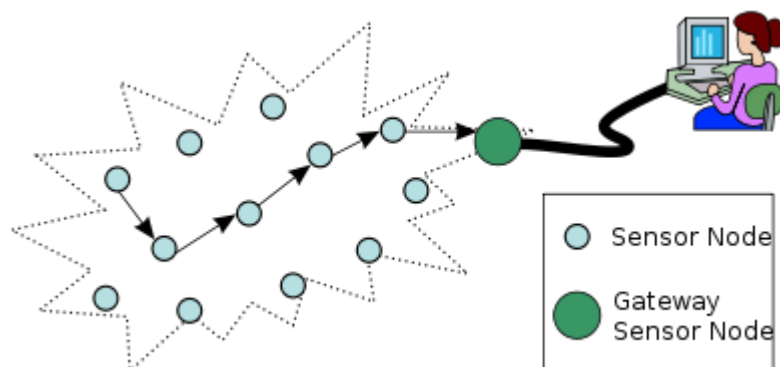
Solar energy can be stored at high temperatures using molten salts. Salts are an effective storage medium because they are low-cost, have a high specific heat capacity and can deliver heat at temperatures compatible with conventional power systems. The Solar Two used this method of energy storage, allowing it to store 1.44 TJ in its 68 m<sup>3</sup> storage tank with an annual storage efficiency of about 99% [19]

#### 2.4.4 Pumped-storage Hydroelectricity

Pumped-storage hydroelectricity stores energy in the form of water pumped when energy is available from a lower elevation reservoir to a higher elevation one. The energy is recovered when demand is high by releasing the water to run through a hydroelectric power generator. [20]

### 3 Introduction to Wireless Sensor Network

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to *monitor* physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, and to cooperatively pass their data through the network to a main location. Figure 2 shows how a wireless sensor network is formed.



**Figure 2** Wireless Sensor network [24]

In computer science and telecommunications, wireless sensor networks are an active research area with numerous workshops and conferences arranged each year

#### 3.1 Characteristics of WSN

The main characteristics of a WSN include: [21]

- Power consumption constrains for nodes using batteries or energy harvesting
- Ability to cope with node failures
- Mobility of nodes
- Dynamic network topology
- Communication failures
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Ability to withstand harsh environmental conditions
- Easy of use
- Unattended operation.

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. They usually consist of a processing unit with limited computational power and limited memory, sensors or MEMS (including specific conditioning circuitry), a communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery. Other

possible inclusions are energy harvesting modules, secondary ASICs, and possibly secondary communication devices. [21]

The base stations are one or more distinguished components of the WSN with much more computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server. Other special components in routing based networks are routers, designed to compute, calculate and distribute the routing tables. Many techniques are used to connect to the outside world including mobile phone networks, satellite phones, radio modems, high power WiFi links etc. [21]

## 3.2 Platforms

### 3.2.1 Standards and Specifications

Several standards are currently either ratified or under development for wireless sensor networks. There are a number of standardization bodies in the field of WSNs. The IEEE focuses on the physical and MAC layers; the Internet Engineering Task Force works on layers 3 and above. In addition to these, bodies such as the International Society of Automation provide vertical solutions, covering all protocol layers. Finally, there are also several non-standard, proprietary mechanisms and specifications. [21]

Standards are used far less in WSNs than in other computing systems. However predominant standards commonly used in WSN communications include:

- ISA100
- IEEE 1451
- ZigBee/ 802.15.4
- IEEE 802.11

### 3.2.2 Hardware

The main challenge in a WSN is to produce *low cost* and *tiny* sensor nodes. There are an increasing number of small companies producing WSN hardware and the commercial situation can be compared to home computing in the 1970s. Many of the nodes are still in the research and development stage, particularly their software. Also inherent to sensor network adoption is the use very low power method for data acquisition. [21]

### 3.2.3 Software

Energy is the scarcest resource of WSN nodes, and it determines the lifetimes of WSNs. WSNs are meant to be deployed in large numbers in various environments, including remote and hostile regions, with ad-hoc communications as key. For this reason, algorithms and protocols need to address the following issues [21]:

- Lifetime maximization
- Robustness and fault tolerance
- Self-configuration

Some of the important topics in WSN software research are:

- Operating systems
- Security
- Mobility
- Usability - human interface for deployment and management, debugging and end-user control
- Middleware - the design of middle-level primitives between high level software and the systems

### 3.3 Distributed Sensor Network

If a centralised architecture is used in a sensor network and the central node fails, then the entire network will collapse, however the reliability of the sensor network can be increased by using distributed architecture. Distributed architecture is used in WSNs for the following reasons [21]:

1. Sensor nodes are prone to failure,
2. For better collection of data
3. To provide nodes with backup in case of failure of the central node

People also take care of nodes sensing redundant information and forwarding the data that is of no use. There is also no centralised body to allocate the resources and they have to be self organised.



## 4 Introduction to Solar Energy Harvesting Development Tool

The eZ430-RF2500-SEH is a complete Solar Energy Harvesting development kit to help create a perpetually powered wireless sensor network based on the ultra-low-power MSP430 microcontroller. Figure 3 shows the main component of the Solar Energy Harvesting Development Tool.



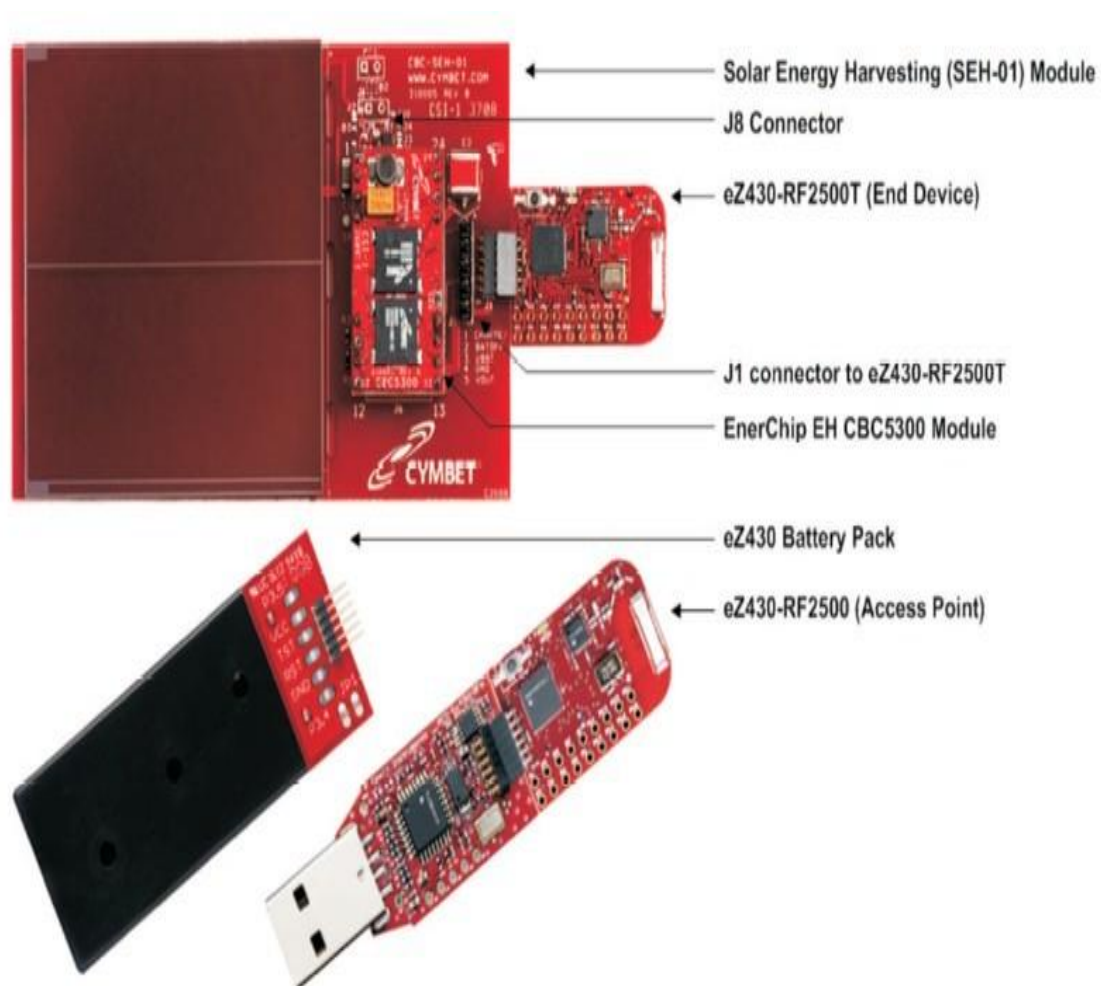
**Figure 3** Solar Energy Harvesting [23]

#### 4.1 Component of eZ430-RF2500-SEH

The components of the eZ430-RF2500-SEH are the following:

- Two eZ430-RF2500T wireless target boards
- One eZ430-RF USB debugging interface
- One AAA battery pack with expansion board (batteries included)
- One SEH-01 Solar Energy Harvesting Board

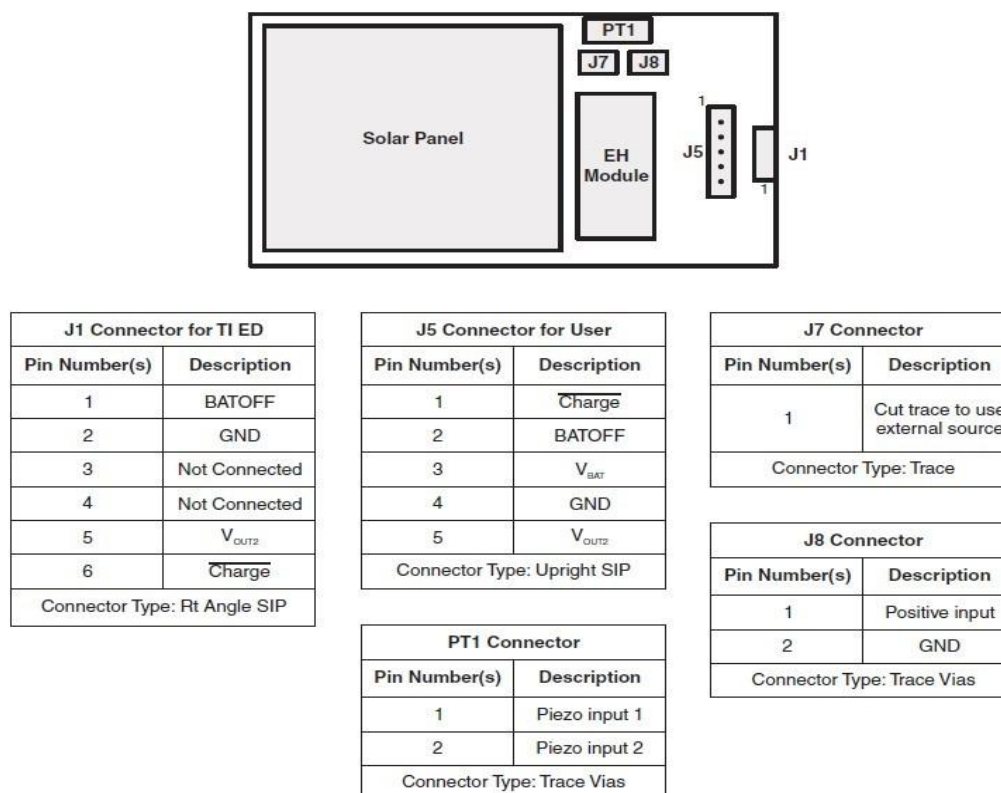
Figure 3.1 shows the components of eZ430-RF2500-SHE.



**Figure 3.1** Solar Energy Harvesting Development Tool [23]

## 4.2 SEH-01 Description

Figure 3.2 shows the connections of the SEH-01 Solar Energy Harvesting Board.



**Figure 3.2** Solar Energy Harvester modules [23]

Solar Energy Harvester modules include [23]:

**J1 Connector:** Connection to the eZ430-RF2500T target board.

**J5 Connector:** Alternate connection point to power an external device or for measuring SEH-01 output levels.

**J7 Connector:** Trace to cut if an alternate solar panel is connected to J8.

**J8 Jumper:** Battery enable jumper—the shunt must be removed before the module is charged. This connector can also be used to connect an alternate solar panel to the SEH-01.

**PT1 Connector:** An alternate piezoelectric energy harvesting transducer can be connected. It can be connected in parallel with the SEH-01 solar panel by leaving J7 intact or the piezoelectric transducer can be used standalone by cutting the J7 trace.

### 4.3 SEH-01 Operating Characteristics

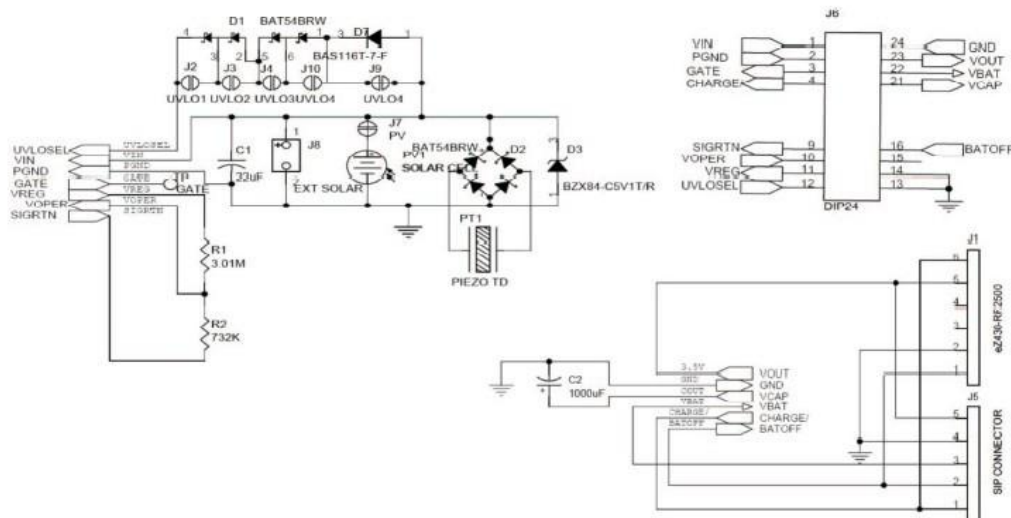
Figure 3.3 shows the operating characteristics of SEH-01.

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT	
Input luminous intensity <sup>(1)</sup>	Minimum operating lux	200			lux	
	Full charge rate	700			lux	
Parasitic load current	Boost converter off		800		nA	
	Boost converter on		20		μA	
Average output power (measured at V <sub>OUT2</sub> pin)	1000 lux (FL), battery not charging		350		μW	
	200 lux (FL), Battery not charging		80		μW	
Output voltage, V <sub>OUT2</sub>	2-μA load, Battery charged	3.5	3.55	3.6	V	
V <sub>BAT</sub> charging voltage			4.06		V	
Battery cutoff voltage		3	3.3	3.6	V	
Pulse discharge current	20 ms		30		mA	
Self discharge rate (non-recoverable average)	25°C, Per year		2.5		%	
Operating temperature			0	25	70	°C
Recharge cycles (to 80% of rated capacity, 4.1-V charge voltage)	25°C	10% depth-of-discharge		5000		
		50% depth-of-discharge		1000		
	40°C	10% depth-of-discharge		2500		
		50% depth-of-discharge		500		
Recharge time (to 80% of rated capacity)	4.1-V constant voltage		500		min	
Capacity	8-μA discharge; 25°C		100		μAh	

**Figure3.3** SEH-01 Operating Characteristics [23]

### 4.4 SEH-01 Circuit Schematic

Figure 3.4 presents the Circuit Schematic of the Solar Energy Harvester Module.



**Figure 3.4** Solar Energy Harvester Module Schematic [23]

## 5 Testing of the Project

### 5.1 Preparing Software Needed in the Project

The Software that is needed includes eZ430-RF2500-SEH Demo and Source Code, eZ430-RF2500-SEH Sensor Monitor Firmware Source, Code Composer Studio v4 Core Edition. All the software available in CDs must be installed on the computer.

### 5.2 Preparing SEH-01

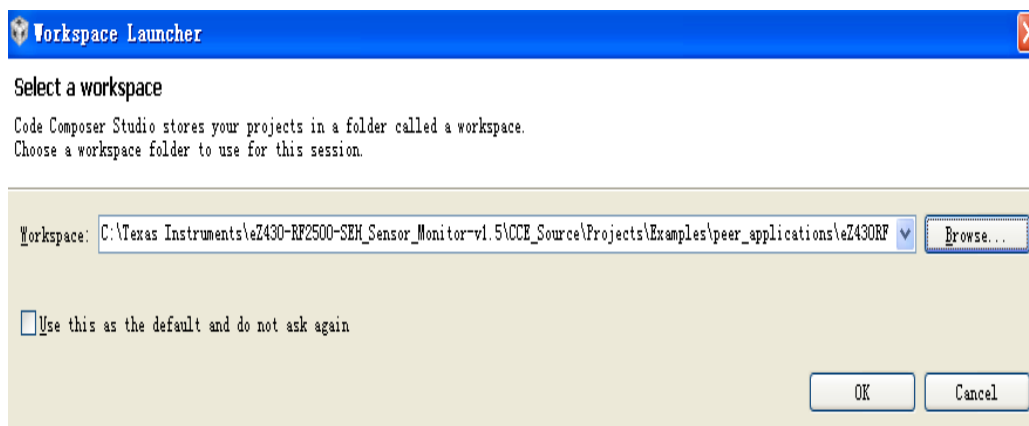
The following steps are taken:

1. Remove the 'Battery Enable Jumper', J8 so that it could get energy from light.
2. Put the SEH in a right location for at least a few minutes so that it can be used for the project. In average indoor lighting, it may take up to one hour to fully charge the system.

### 5.3 Setting up the CCE Project

The following steps are taken:

1. Open Code Composer Studio v4.
2. Open the Code composer Studio v4. Remember Open the Workspace in C:\Texas Instruments\eZ430-RF2500-SEH\_Sensor\_Monitor-v1.5\CCE\_Source\Projects\Examples\peer\_application\Ez430RF. Figure 4.1.0 shows Open Code Composer Studio v4 in the right workspace.



**Figure 4.1.0** Code Composer Studio v4 workspace

3. Click Project > Import Existing CCS/CCE Project. Ensure "SEH Sensor Monitor" is selected under Projects. Figure 4.1.1 shows the selecting of Import Existing CCE Project.

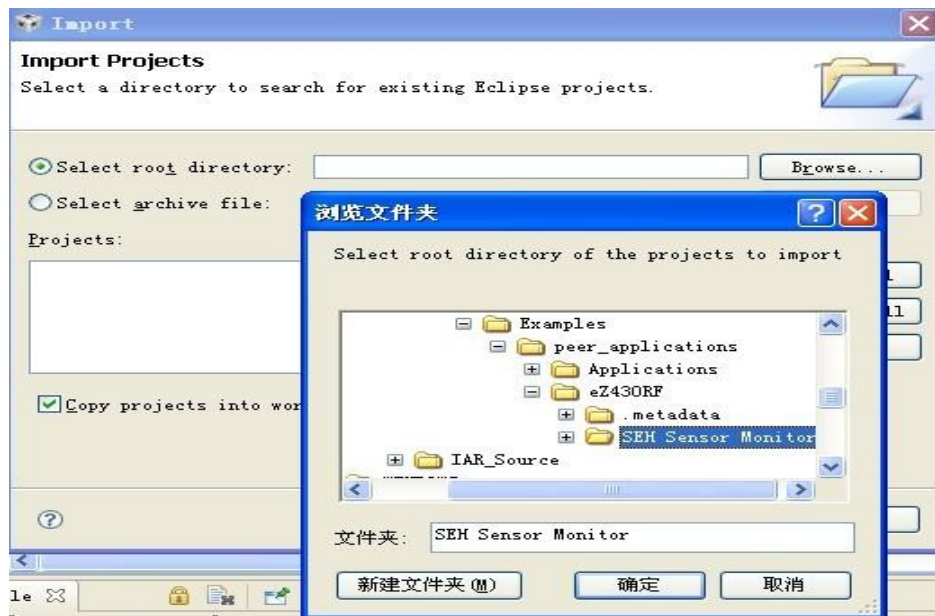


Figure 4.1.1 Import Projects

4. Click window to preferences then take New project. This is named DEV\_ROOT. Choose the file which has been installed in the computer. Remove the CCS fold; otherwise it is impossible to run the CCE project. Figure 4.1.2 shows the following step Edit Variable resources.

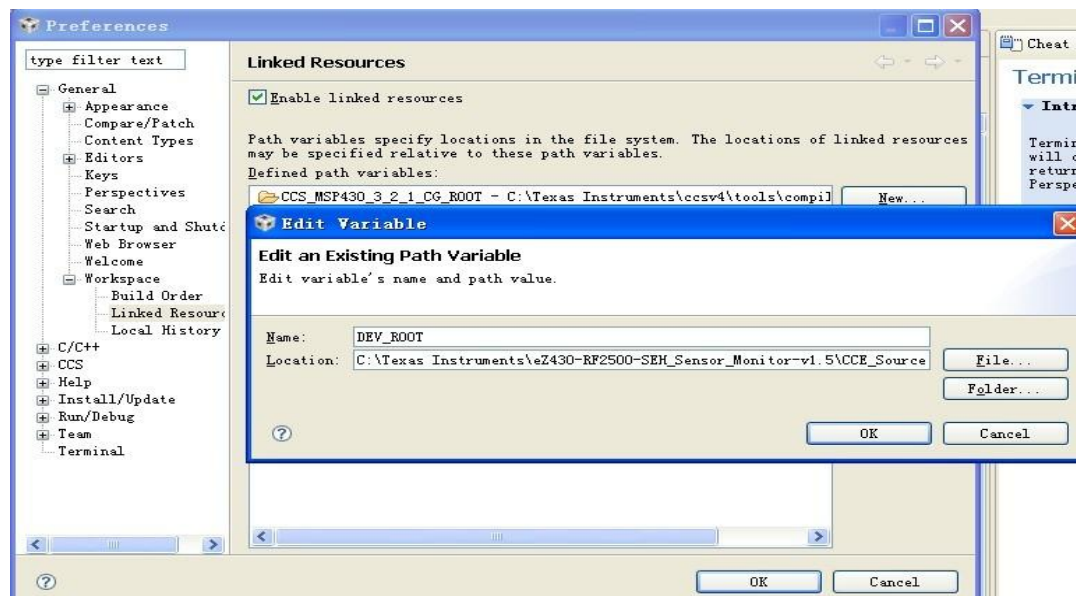
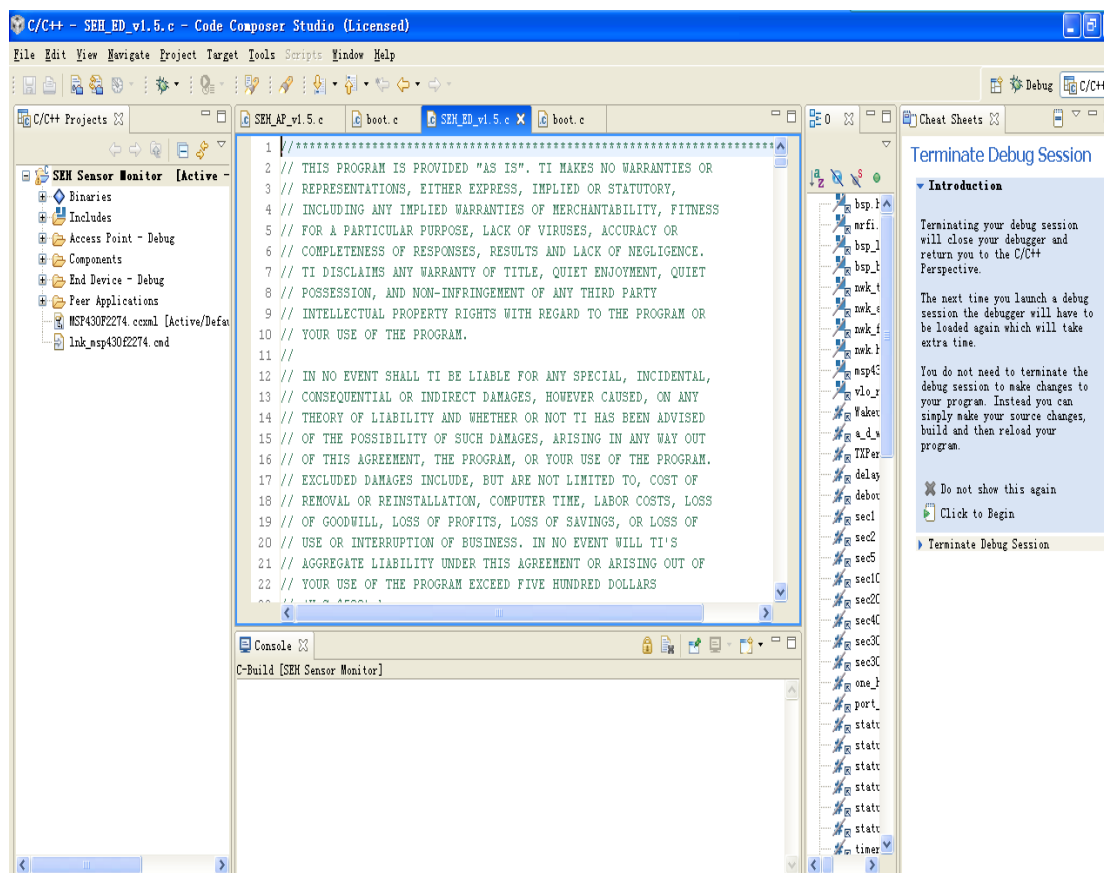


Figure 4.1.2 Linked Resources



Figure 4.1.3 presents a Window of the Code Composer Studio v4.



**Figure 4.1.3** Code Composer Studio v4

## 5.4 Debugging End Device and Access Point

The following steps are taken:

1. Connect the Connect eZ430-RF2500T target boards to the USB Debugging interface on computer.
2. Right-click the project name "SEH Sensor Monitor" in the C/C++ Projects window and click Active BuildConfiguration > End Device - Debug.
3. Click Project > Clean...
4. Click Target > Debug Active Project.

Figure 4.1.4 shows the Window of Debug End Device.

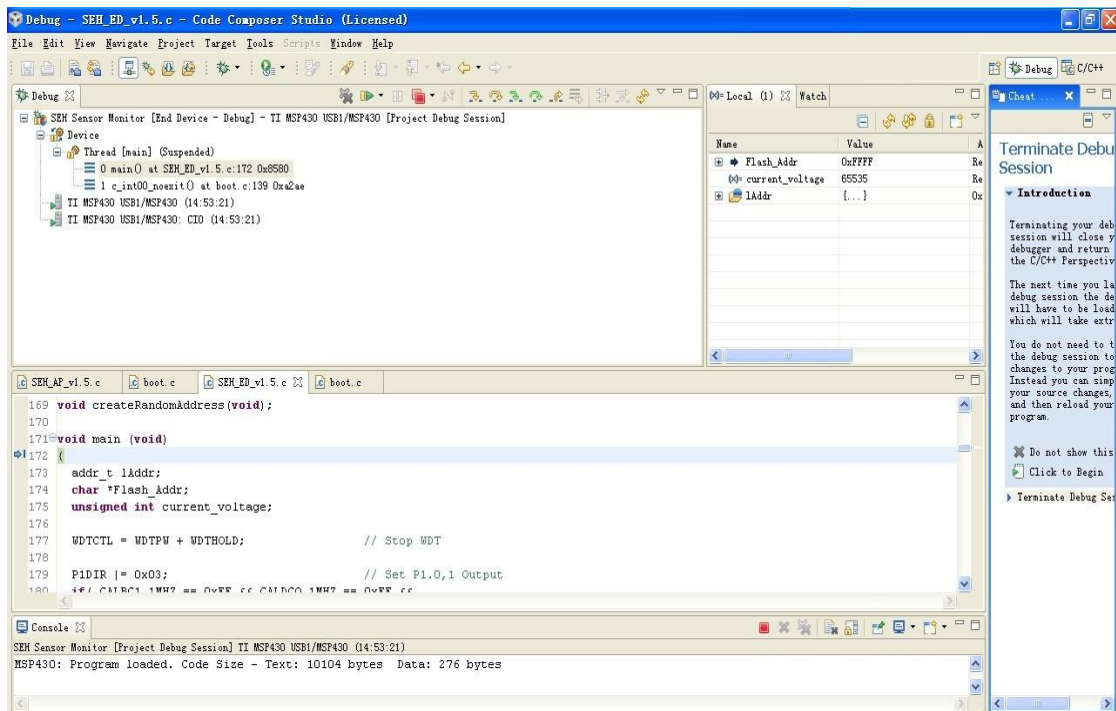


Figure 4.1.4 Debug End Device

Then click green button to run it. Figure 4.1.5 shows the C++ Window.

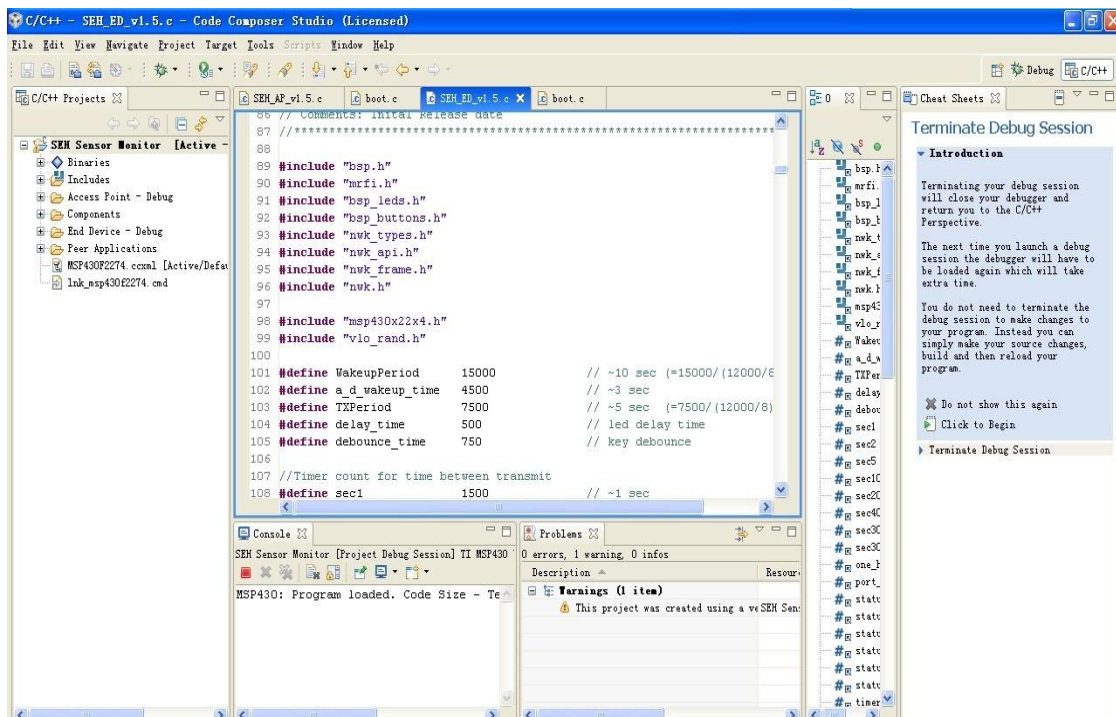
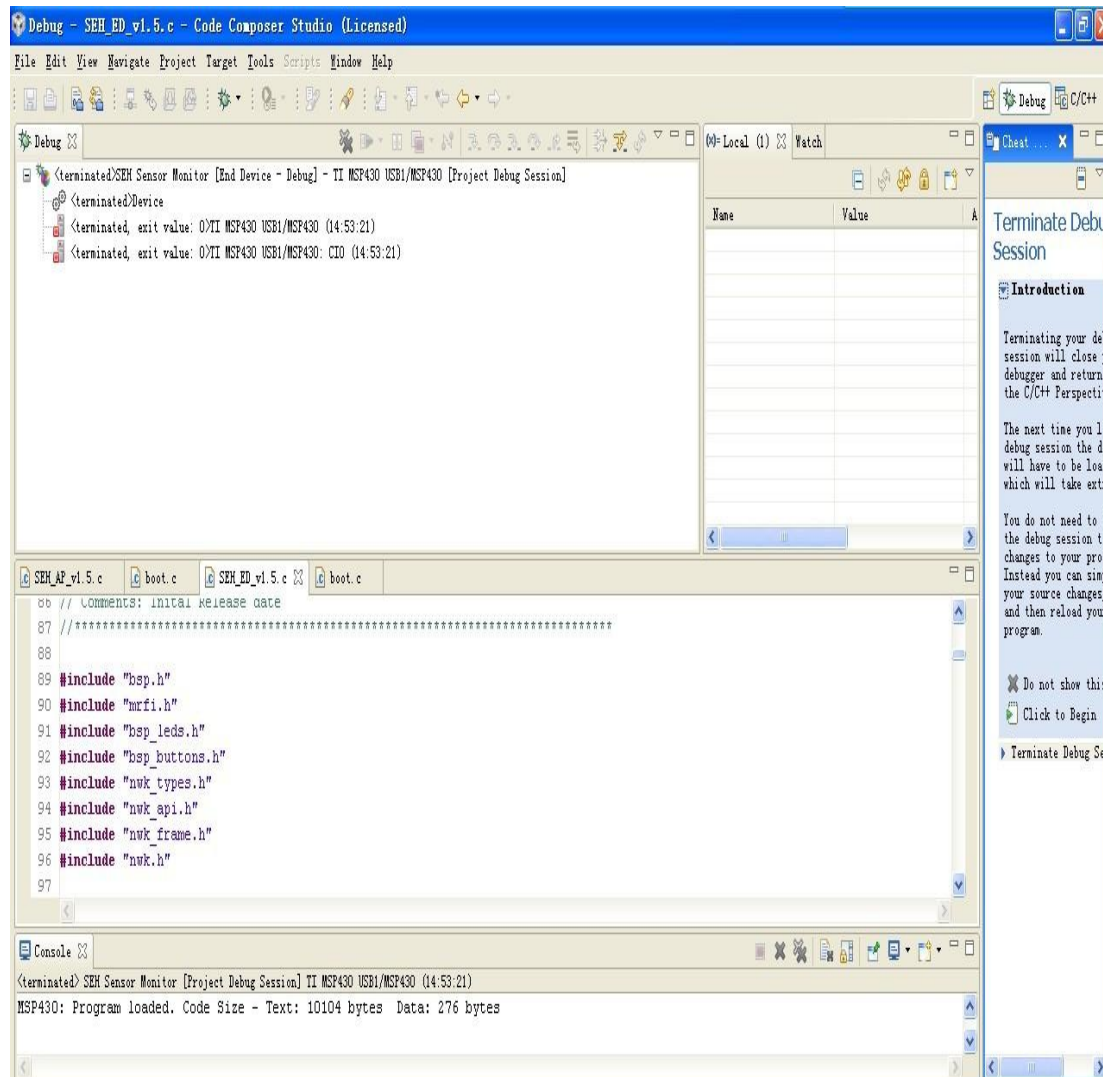


Figure 4.1.5 C++ Window



6. Click the Terminate button to terminate the debugging session. Figure 4.1.6 shows Terminate the debugging session.



**Figure 4.1.6** Terminate the debugging session

7. Remove the eZ430-RF2500 target board from the emulator. It has now been programmed as the End Device. And connect the other target board to emulator

8. Right-click the "SEH Sensor Monitor" project name in the C/C++ Projects window and select Active Build Configuration > Access Point - Debug.

9. Click Project > Clean...

10. Click Target > Debug Active Project

Figure 4.1.7 shows debugging the Access Point.

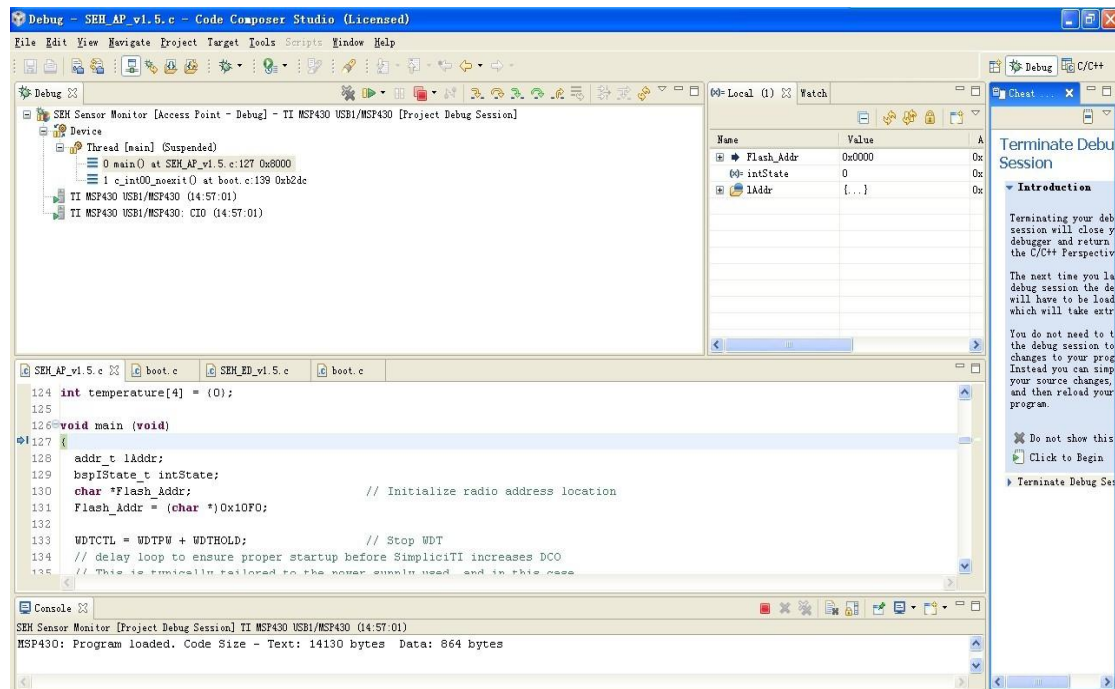


Figure 4.1.7 Debug Access Point

Then click the green Run arrow button to run it.

Figure 4.1.8 shows running the Access Point.

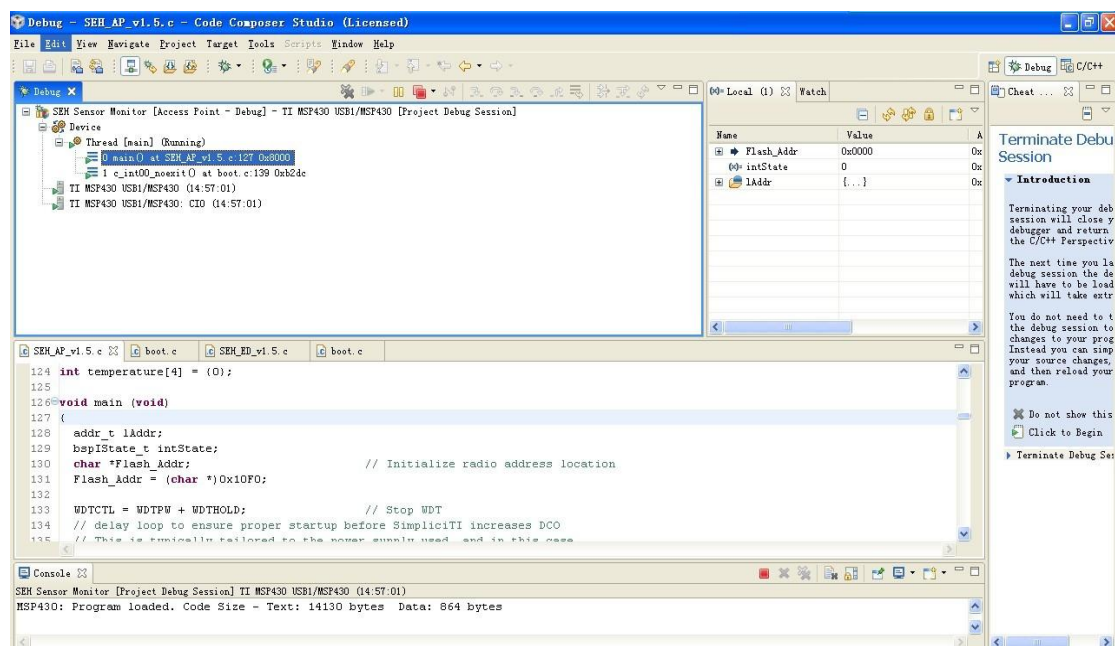


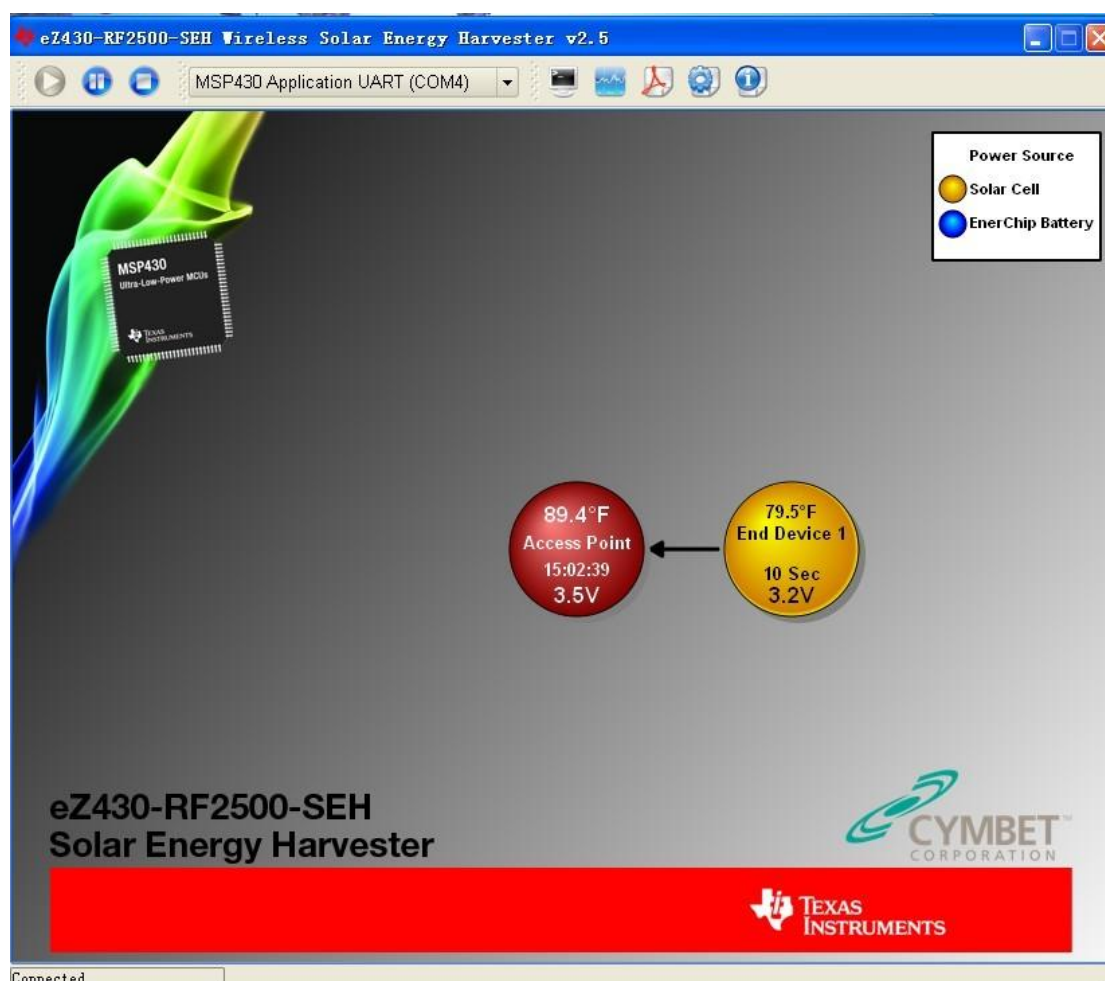
Figure 4.1.8 Run Access Point

## 6 Results of the Project

Finally, connect the first eZ430-RF2500T (End Device) target board to the battery pack or the Solar Energy Harvesting board. Open the eZ430-RF2500 Sensor Monitor PC program which has been installed on the PC to watch the network form and receive data from the wireless node.

### 6.1 PC Sensor Monitor Applications

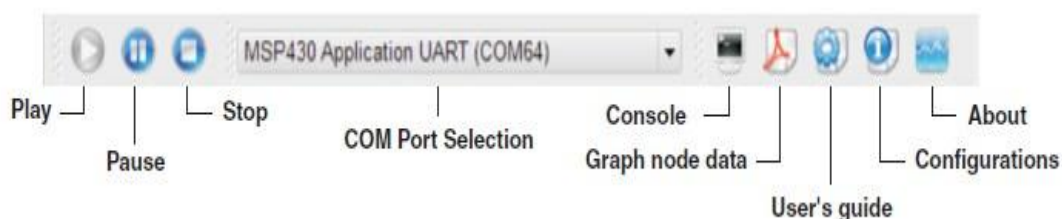
Figure 5.1.0 shows this network consists of an Access Point that measures its own temperature and a wirelessly receives temperature measurements from End Devices. End Devices measure their temperature once per second and then enter a low-power mode to reduce battery usage. The Access Point transmits all measured data to the PC through the UART backchannel.



**Figure 5.1.0** PC Sensor Monitor Applications

## 6.2 Menu Bar

Menu Bar is used to control the PC Sensor Monitor Applications. Figure 5.2 shows the configuration for menu bar.



**Figure 5.2** Menu Bar

## 6.3 Console Window

Figure 5.3 shows that the console session for network. View a real time output of all node data. Node: Hub0 is access point. Node: 0001 is End Device.

```

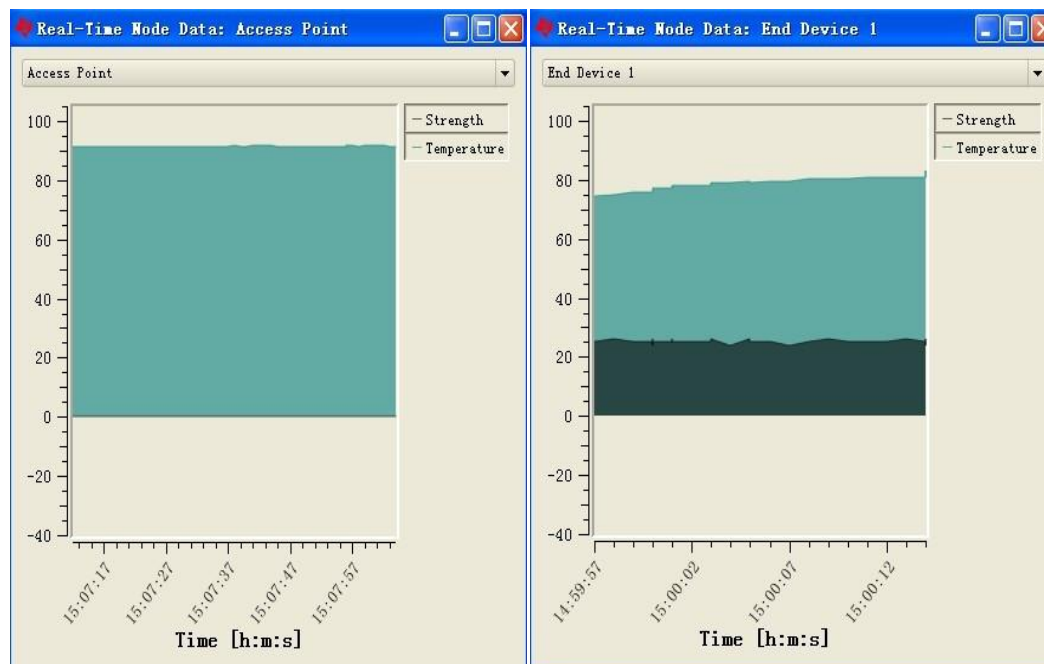
Log.txt* - Console Session
File Edit Select Nodes
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:14
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:15
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:16
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:17
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:18
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:19
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:20
Node:Hub0,Temp: 90.3F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:20
Node:0001,Temp: 90.8F,Battery: 3.2V,Strength:024%,RE:0101400 , 4/25/2011, 15:04:20
Node:Hub0,Temp: 90.3F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:21
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:22
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:23
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:24
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:25
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:26
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:27
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:27
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:28
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:29
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:30
Node:0001,Temp: 90.8F,Battery: 3.2V,Strength:024%,RE:0101400 , 4/25/2011, 15:04:30
Node:Hub0,Temp: 90.5F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:31
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:32
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:33
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:34
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:34
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:35
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:36
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:37
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:38
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:39
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:40
Node:0001,Temp: 90.8F,Battery: 3.3V,Strength:025%,RE:0101400 , 4/25/2011, 15:04:40
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:41
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:42
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:42
Node:Hub0,Temp: 90.6F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:43
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:44
Node:Hub0,Temp: 90.8F,Battery: 3.5V,Strength:000%,RE:0100000 , 4/25/2011, 15:04:45

```

**Figure 5.3** Console Window

## 6.4 Graph Window

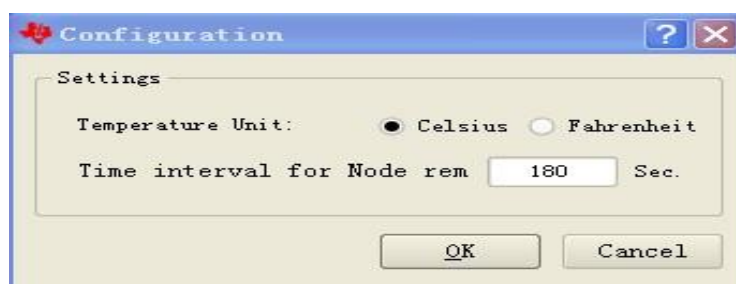
Temperature data and RF signal strength (RSSI) for all nodes can be plotted in a graph window. The signal strength is displayed as a percentage. The last 60 transmissions are stored and displayed. Only 24 hours worth of data can be displayed. Below Figure 5.4 it is that the temperature, strength of Access Point and End Device 1.



**Figure 5.4** Graph Windows of Access Point and End Device 1

## 6.5 Configurations

Figure 5.5 shows the configurations of PC Sensor Monitor Applications. Use the configuration to change Temperature Unit and Time interval for Node remaining.



**Figure 5.5** Configurations



## 7 Testing of Different Conditions

### 7.1 Changing the Transmission Duty Cycle

Push the button on the End Device to change the transmission duty cycle in 20 seconds intervals. It has little fluctuation in temperature and strength. Figure 6.1.0 shows the network running at 20 second intervals.

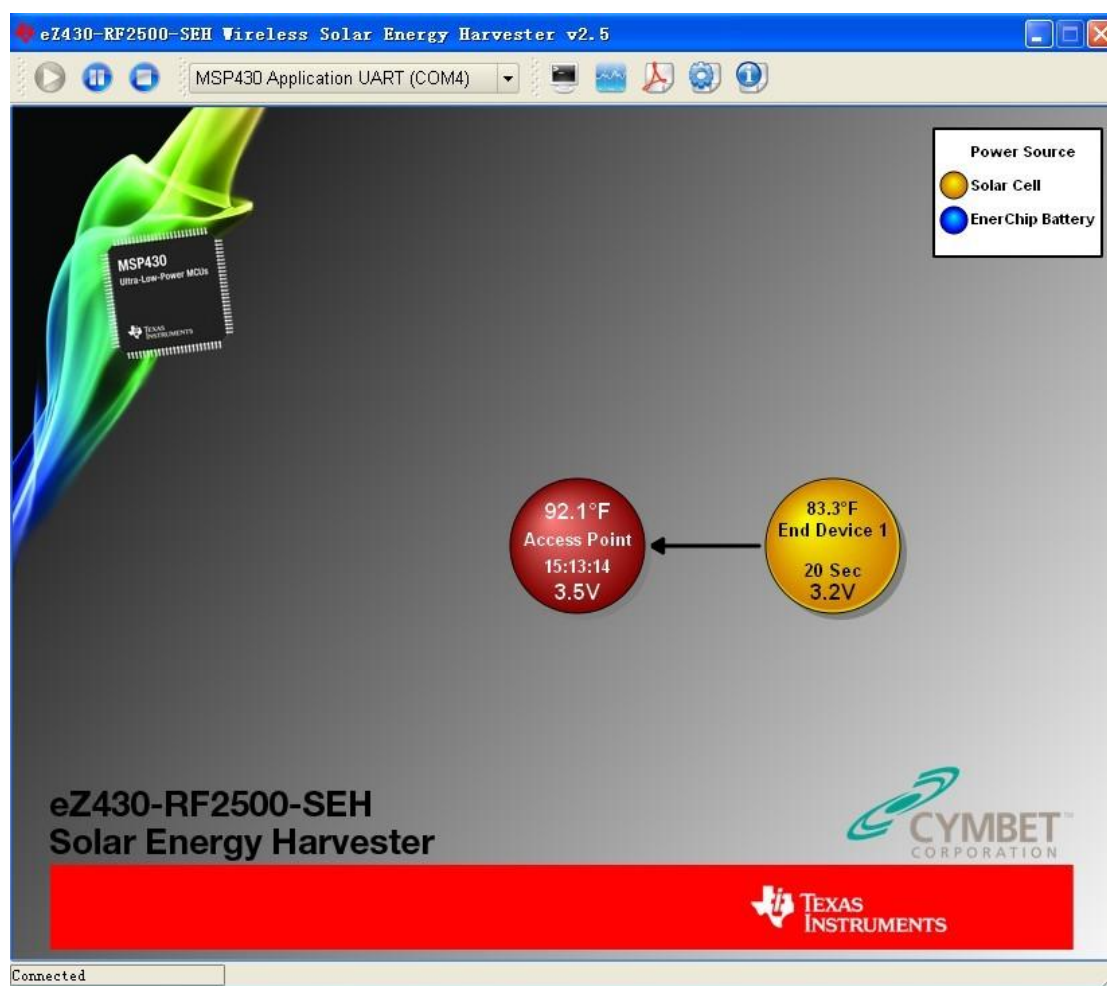


Figure 6.1.0 PC Sensor Monitor Applications

Figure 6.1.1 shows the console session of network at 20 second intervals.

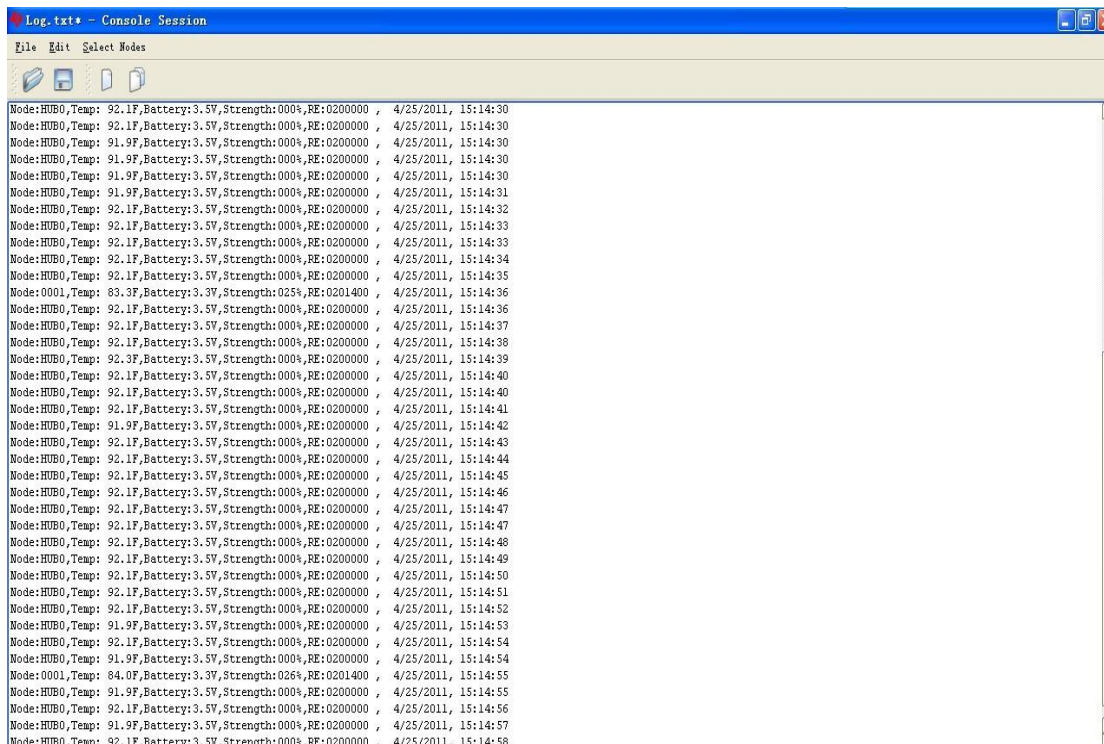


Figure 6.1.1 Console Window

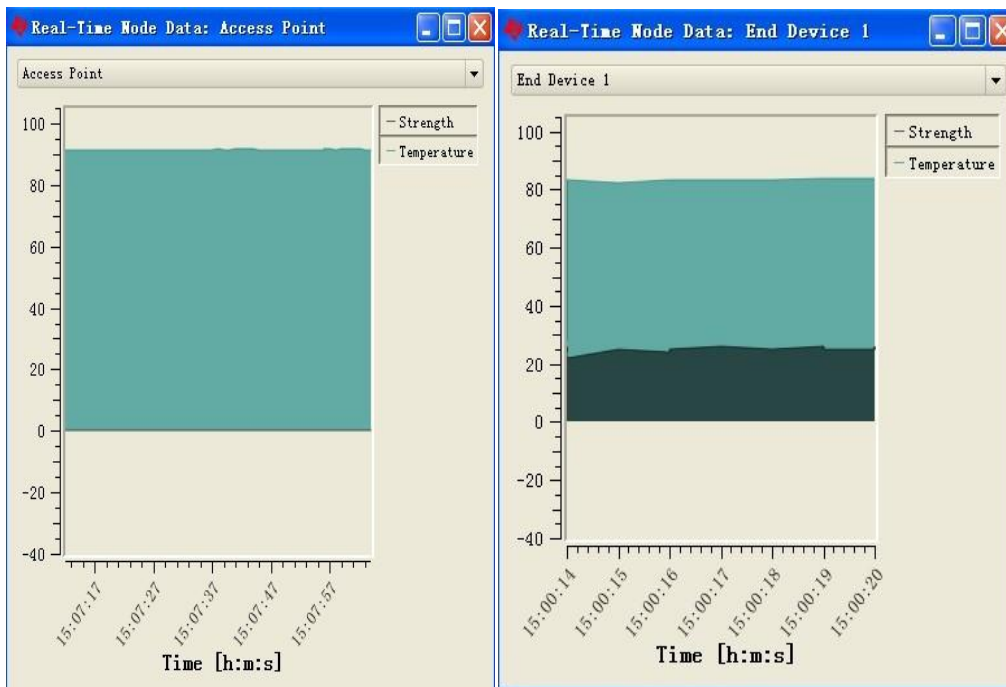
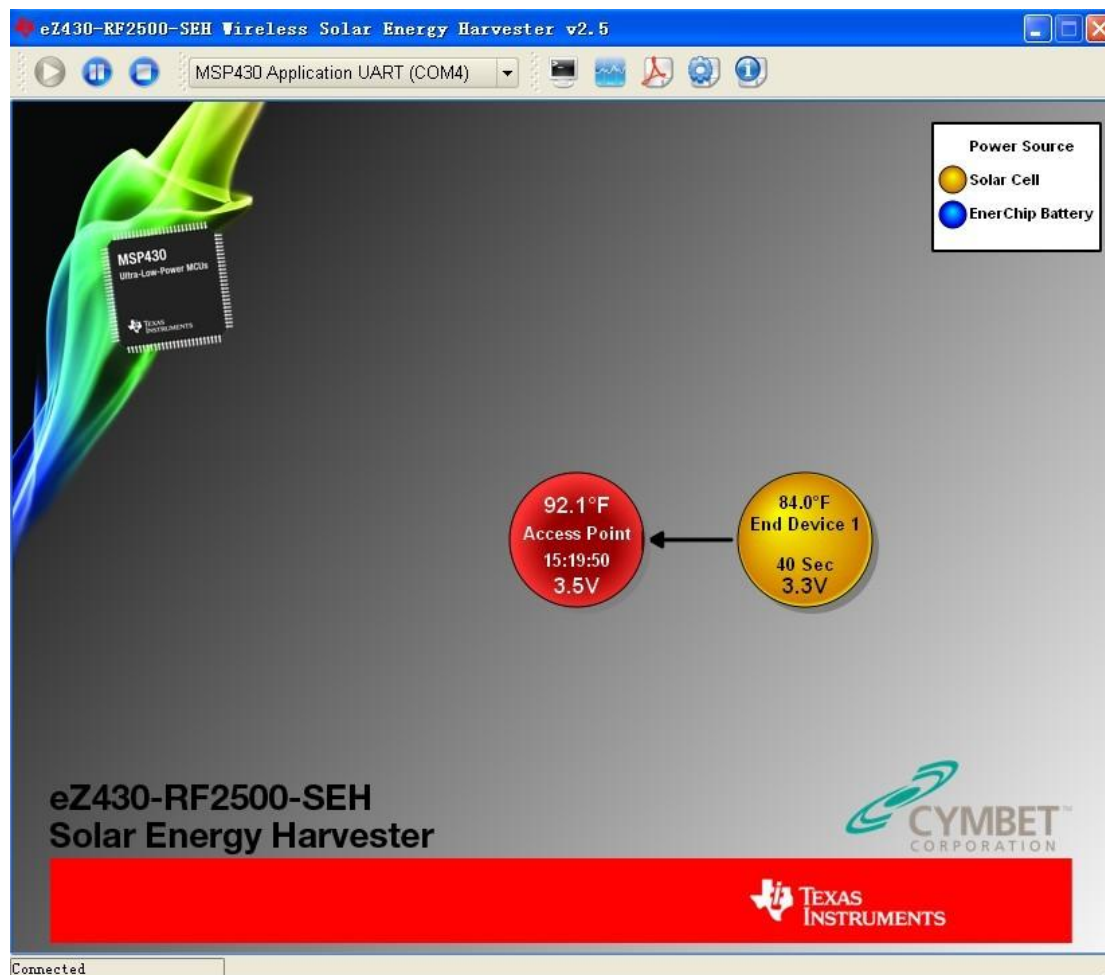


Figure 6.1.2 Graph Window

Figure 6.1.2 presents the temperature, strength of Access Point and End Device 1.

## 7.2 Charging the SEH-01 from Sunlight

It also has little fluctuation in fluctuation in tempertuare and strength. Below in Figure 6.2.0 shows the network running after charging the SEH-01 from Sunlight.



**Figure 6.2.0** PC Sensor Monitor Applications



Figure 6.1.1 shows the console session of network.

```

Log.txt* - Console Session
File Edit Select Nodes
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:01
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:02
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:02
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:03
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:04
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:05
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:06
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:07
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:08
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:09
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:09
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:10
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:11
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:12
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:13
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:14
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:15
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:16
Node:HUB0,Temp: 91.9F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:16
Node:HUB0,Temp: 91.9F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:17
Node:HUB0,Temp: 91.9F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:18
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:19
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:20
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:21
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:22
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:23
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:23
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:24
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:25
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:26
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:27
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:28
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:29
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:30
Node:0001,Temp: 64.0F,Battery:3.3V,Strength:025%,RE:0401400 , 4/25/2011, 15:20:30
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:30
Node:HUB0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:31
Node:HUB0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:32
Node:HUB0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0400000 , 4/25/2011, 15:20:33

```

Figure 6.2.1 Console Window

Figure 6.2.2 shows the temperature, strength of Access Point and End Device 1.

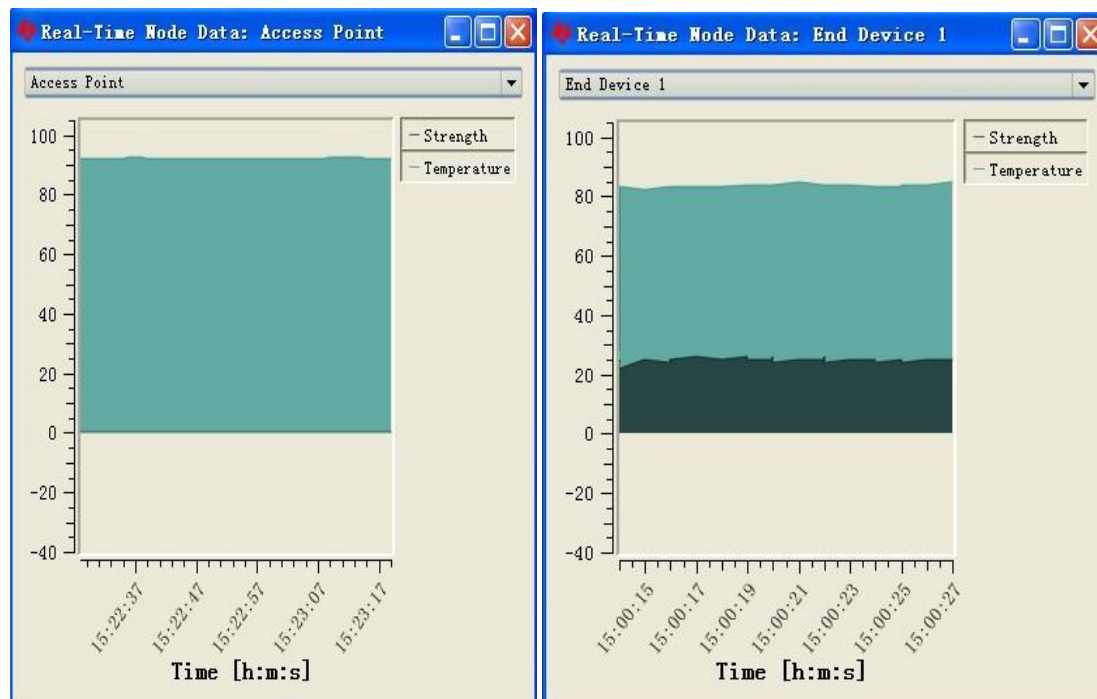
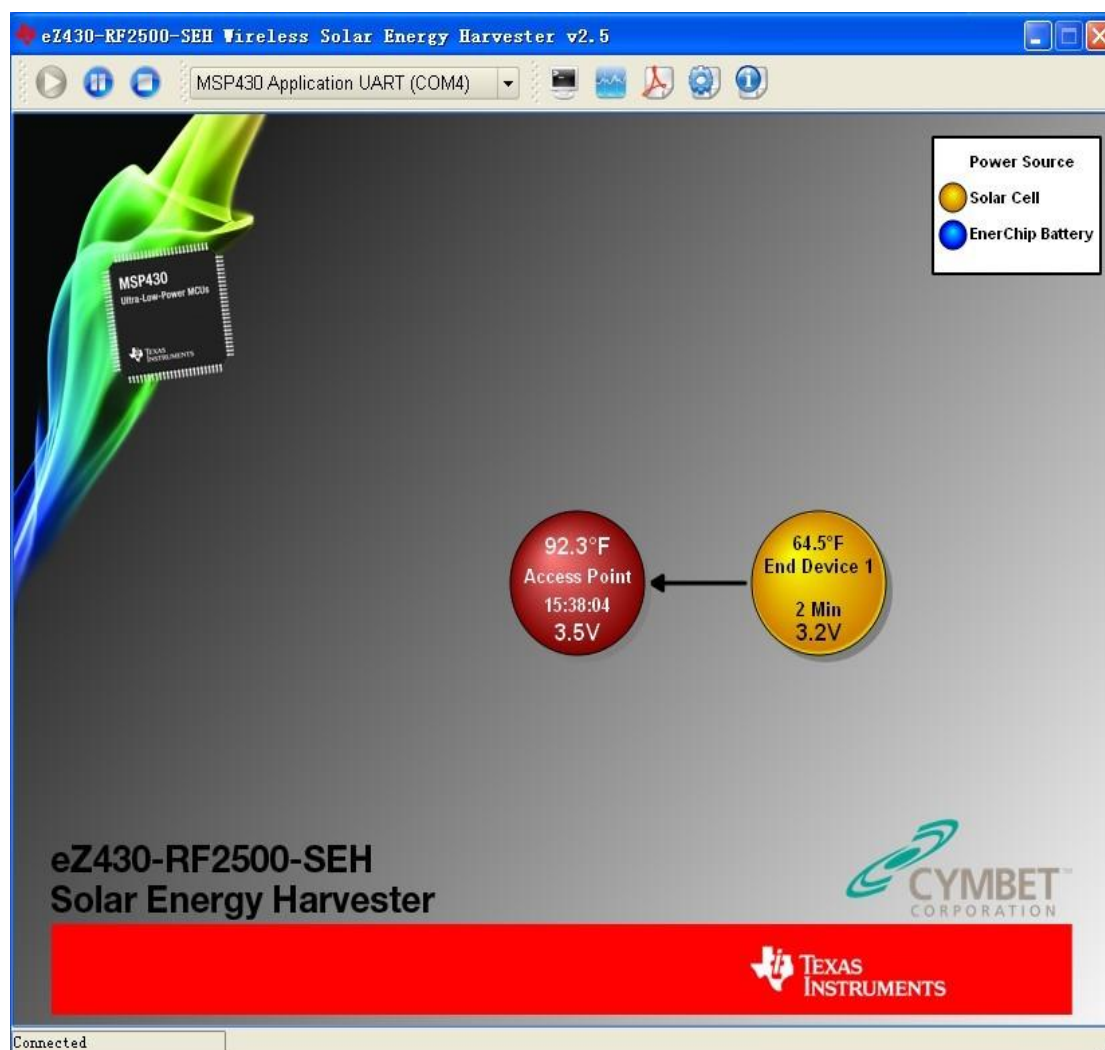


Figure 6.2.2 Graph Window

### 7.3 Charging the SEH-01 from Fluorescent lamp

After charging the SEH-01 from Fluorescent lamp, it has a little fluctuation in temperature and strength, but not much. Figure 6.3.0 shows the PC Sensor Monitor Applications.



**Figure 6.3.0** PC Sensor Monitor Applications

Figure 6.3.1 shows the console session of network. View a real time output of all node data. Node: Hub0 is access point.

```

Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:25
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:26
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:26
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:27
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:28
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:29
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:30
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:31
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:32
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:33
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:33
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:34
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:35
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:36
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:37
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:38
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:39
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:40
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:40
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:41
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:42
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:43
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:44
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:45
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:46
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:47
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:47
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:48
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:49
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:50
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:51
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:52
Node:Hub0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:53
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:54
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:54
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:55
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:56
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0020000 , 4/25/2011, 15:38:57

```

Figure 6.3.1 Console Window

Figure 6.3.2 shows the temperature, strength of Access Point and End Device 1. The temperature, strength of End Device 1 has a little fluctuation.

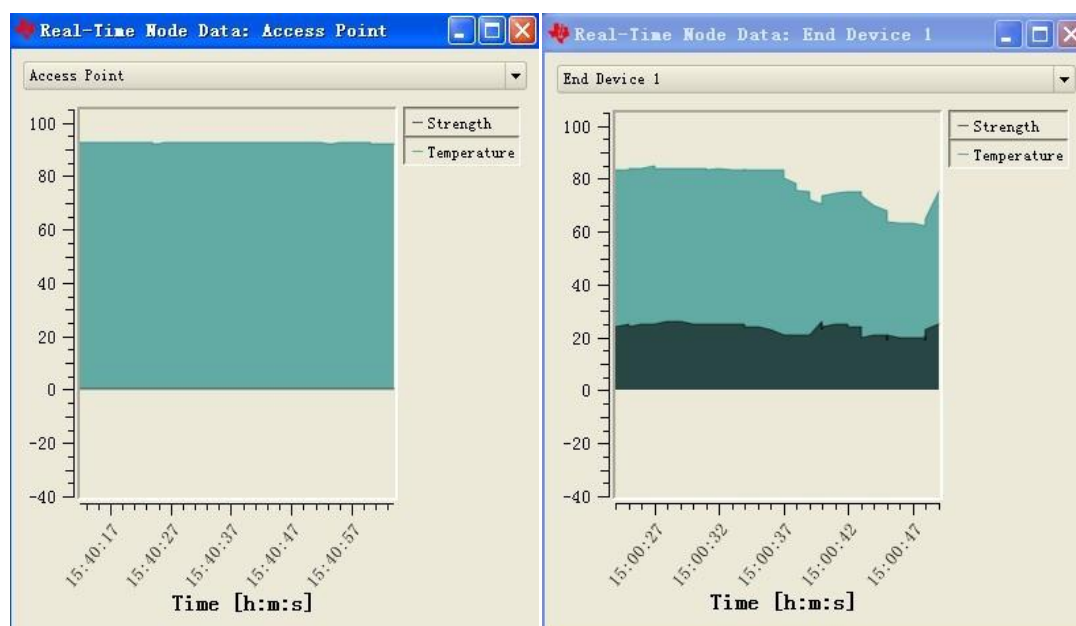


Figure 6.3.2 Graph Window

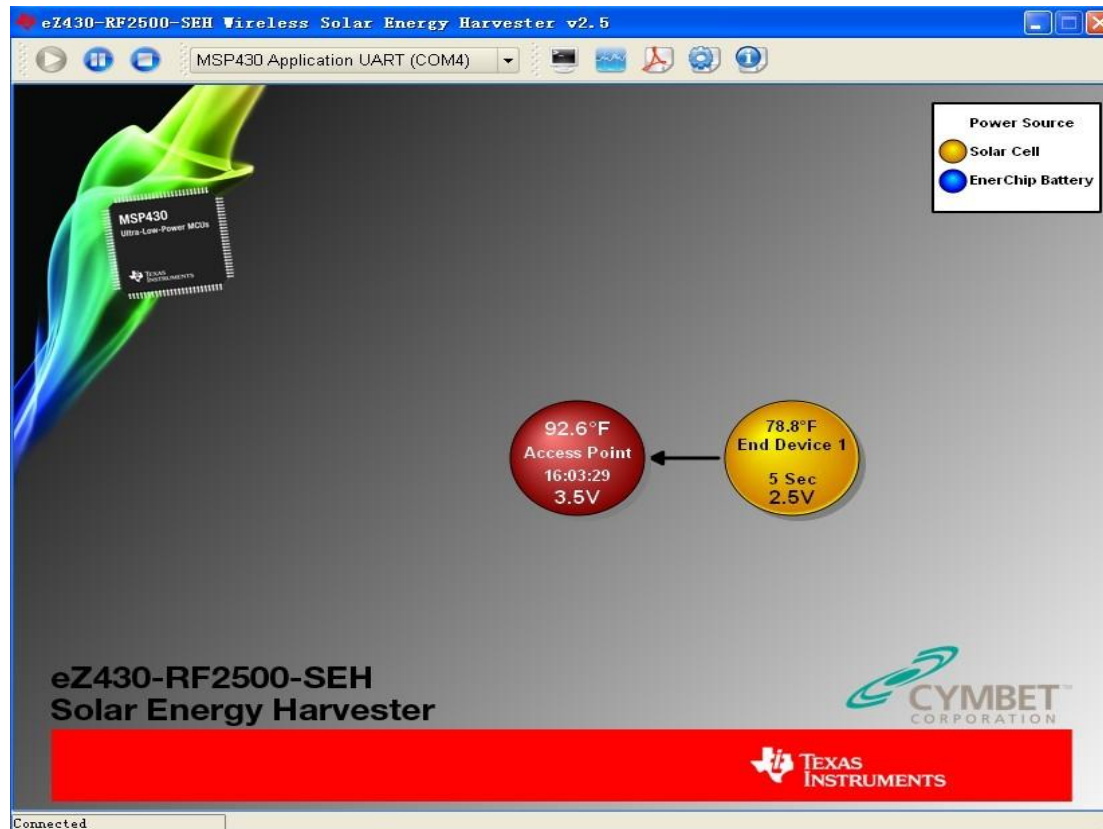
### 7.3.1 Testing of Two Different Lamps

In first lamps condition, first start the project at 14:40:41. Put the development tool under the lamp. It can create the power to run wireless sensor for everytime. Cover the panel at 16:34:13. Then the End Device was running on an enerchip battery. It last almost 1 hour to run wireless sensor application. It stops running the application at 17:36:25.

In second lamps condition, first start the project at 18:47:09. Put the development tool under the lamp. It can create the power to run wireless sensor for everytime. Cover the panel at 20:00:06. Then the End Device is running on an enerchip battery. It last almost 1 hour to run wireless sensor application. It stops running the application at 21:06:00.

### 7.4 Changing the range between SEH-01 and Computer

Change the range between SEH-01 and Computer in 50 meters. It has much fluctuation in temperature and strength. Figure 6.4.0 shows the PC Sensor Monitor Applications.



**Figure 6.4.0** PC Sensor Monitor Applications

Figure 6.3.1 shows the console session of the network. View a real time output of all node data. Node: Hub0 is access point. Node: 0001 is end device 1.

```

Log.txt* - Console Session
File Edit Select Nodes

Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:39
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:40
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:41
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:42
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:43
Node:0001,Temp: 76.4F,Battery:2.9V,Strength:025%,RE:1051399 , 4/25/2011, 16:03:43
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:44
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:45
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:46
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:46
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:47
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:48
Node:0001,Temp: 75.7F,Battery:3.1V,Strength:025%,RE:1051398 , 4/25/2011, 16:03:48
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:49
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:50
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:51
Node:Hub0,Temp: 92.8F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:52
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:03:53
Node:0001,Temp: 75.7F,Battery:3.2V,Strength:025%,RE:0051399 , 4/25/2011, 16:03:53
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:53
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:54
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:55
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:56
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:57
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:58
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:025%,RE:0051400 , 4/25/2011, 16:03:58
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:03:59
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:00
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:00
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:01
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:02
Node:Hub0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:03
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:025%,RE:0051400 , 4/25/2011, 16:04:03
Node:Hub0,Temp: 92.1F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:04
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:05
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:06
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:0050000 , 4/25/2011, 16:04:07

```

Figure 6.4.1 Console Window

Figure 6.4.2 shows the temperature, strength of Access Point and End Device 1. It has much fluctuation.

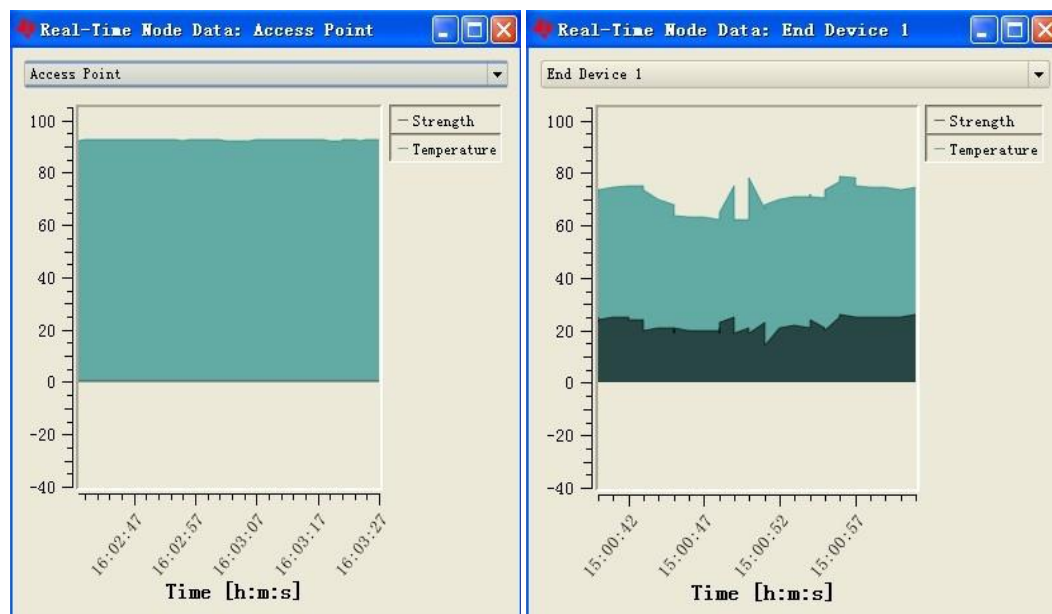
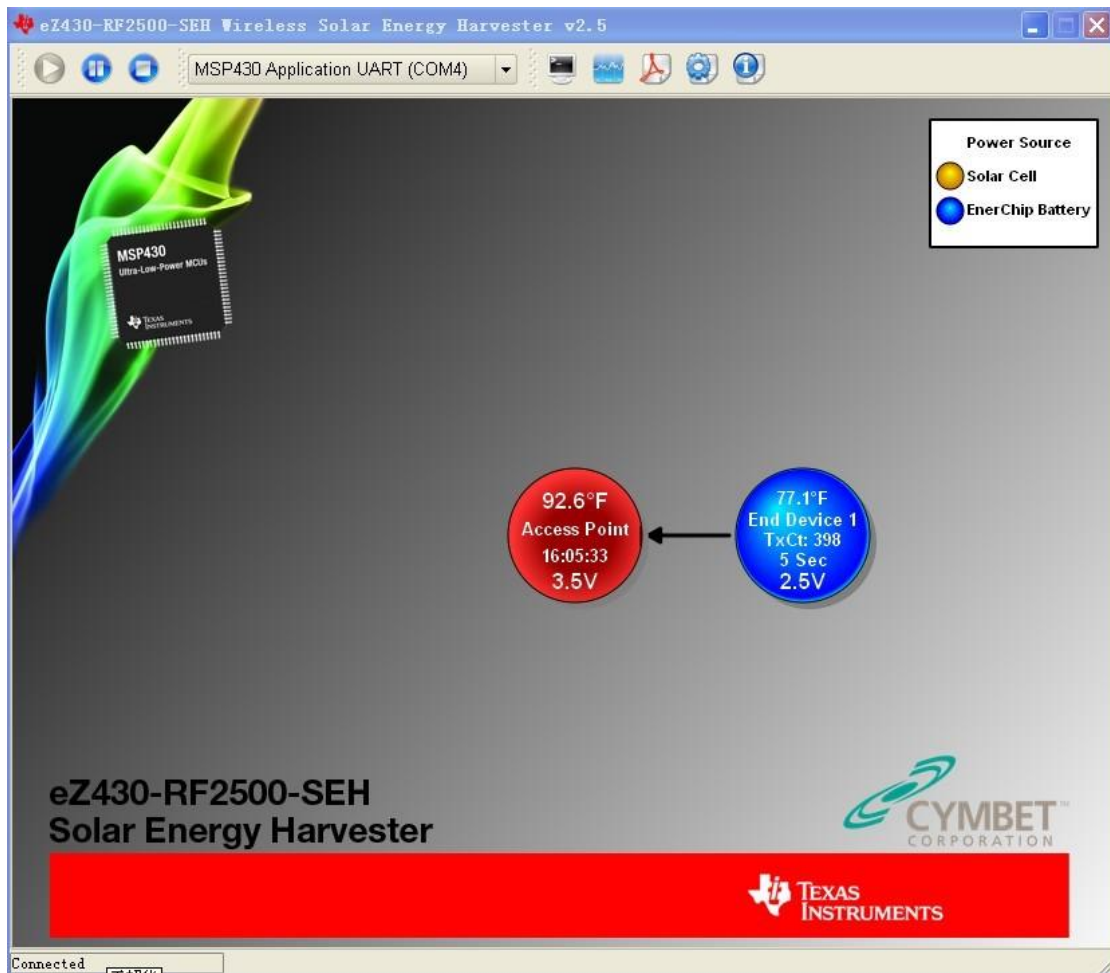


Figure 6.4.2 Graph Window



## 8 EnerChip Battery

Covering the solar panel to force the system run from the stored energy, Txct is the number of RF transmissions remaining when the End Device is running on an Enerchip Battery. Figure 7.1.0 shows the network running by EnerChip Battery.



**Figure 7.1.0** Ener Chip Battery

**Figure 7.1.1** shows the console session of network. View a real time output of all node data. Node: Hub0 is access point. Node: 0001 is end device 1.

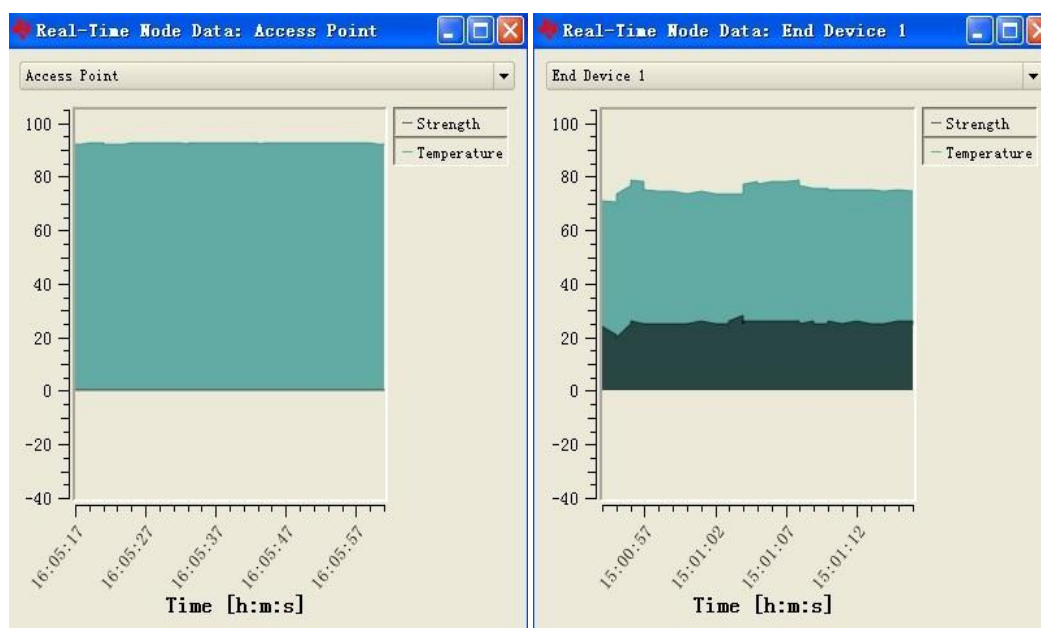
```

Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:05
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:06
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:09
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:09
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:026%,RE:1051398 , 4/25/2011, 16:06:09
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:09
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:09
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:10
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:11
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:12
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:13
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:026%,RE:1051397 , 4/25/2011, 16:06:13
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:14
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:15
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:15
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:16
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:17
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:025%,RE:1051396 , 4/25/2011, 16:06:18
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:18
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:19
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:20
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:21
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:22
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:22
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:026%,RE:1051395 , 4/25/2011, 16:06:23
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:23
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:24
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:25
Node:Hub0,Temp: 92.3F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:26
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:27
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:28
Node:0001,Temp: 75.0F,Battery:3.2V,Strength:026%,RE:1051394 , 4/25/2011, 16:06:28
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:29
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:30
Node:Hub0,Temp: 92.6F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:30
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:31
Node:Hub0,Temp: 92.4F,Battery:3.5V,Strength:000%,RE:1050000 , 4/25/2011, 16:06:32

```

**Figure 7.1.1** Console Window

Figure 7.1.2 shows the temperature, strength of Access Point and End Device 1.



**Figure 7.1.2** Graph Window

The core technology of the Solar Energy Harvesting module is the photovoltaic or solar cell that converts ambient light into electrical energy. The EnerChip EH CBC5300 which is the small DIP mounted board on the Solar Energy Harvesting Module (SEH-01) convert, manage and store the energy from the solar cell. A boost converter is used to increase the voltage from the solar cell to a sufficient level to charge the thin-film battery and run the rest of the system.

The Charge Control block continuously monitors the output of the boost converter. If the output of the boost converter falls below the voltage needed to charge the EnerChip, the charge controller disconnects the boost converter from the system to prevent back powering the boost converter in low light conditions.

The Power Management block prevents the EnerChip from discharging too deeply in low-light conditions or under abnormally high current loads. It also ensures that the load is powered up with a smooth power-on transition. The Power Management block has a control line, CHARGE, which indicates to the MSP430 that the solar energy harvester is actively charging the EnerChip. The control line input, BATOFF, is available for the MSP430 to isolate itself from the EnerChip to conserve battery life in prolonged low-light conditions.

The Solar Energy Harvesting Module features two EnerChip batteries mounted on the board with a 100-mAhr capacity and a 1,000-mF capacitor for high-current pulses during wireless transmissions.

Using the power management status and control signals on the SEH-01, the firmware on the MSP430 has been written to make the application 'Energy Aware' to maximize the overall lifetime of the system. [23]



## 9 Conclusions

In this project the SEH module's solar panel was optimized for operating lights, which provides enough power to run a wireless sensor application with no additional batteries. The ez430-Rf2500 is used to run the energy harvesting application. It is also the interface to transfer data to PC from the wireless system. Different light have no effect on the solar energy harvesting development tool. There were changes only based on the range between the SEH-01 and Computer port.

The core technology behind the Solar Energy Harvesting development tool is the photovoltaic or solar cell that converts ambient light into electrical energy. The energy from the solar cell must be converted, managed and stored. This process is handled by EnerChip EH CBC5300 which is on the SEH-01.

This project was full of challenges. However, this project was a good opportunity to study in practice. Firstly, more knowledge about solar energy was studied. Secondly, a wireless sensor network was improved. Finally, these two areas were combined and it was studied to use the solar energy harvesting in a wireless sensor network with the development tool. This was a huge learning experience in life.

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