Efficient HVAC System

Group 6

Sponsored by AC3 Development Group LLC

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Motivation

- HVAC systems are one of the leading energy consuming appliances in use in any building.
- With the recent push toward green technology, there is a new demand for a more efficient, and affordable HVAC control system.
- There has also become a need for an HVAC system that introduces filtered outside air into the building in order to provide the occupants enhanced air quality.
Project Overview

- A more efficient HVAC control system to save the user money on a monthly basis through reduced power consumption
- A user friendly interface through a wall mount touch screen thermostat with web connectivity that allows settings to be viewed and changed from a mobile device
Objectives

- Accurately read temperature and relative humidity both inside and outside building.
- Wirelessly transmit outside data to the main control unit.
- User interface must be a thermostat replacement in the form of a touch screen that is easy to view and intuitive to operate.
- Communicate with the internet so that the user can view and manipulate system settings from a remote location via mobile device.
- Must be expandable to incorporate additional HVAC components and sensors.
Objectives

- Allow the user to input desired temperature and relative humidity set points
- Determine the most efficient components to use to heat or cool the building based on settings ranging from “max comfort” to “max savings”
- Display the current percentage of the total system energy being used via an “energy usage” bar
- Allow the user to view current power consumption
- Allow the user to input a specific tolerance level for each comfort setting
- Expandable coding to incorporate HVAC systems consisting of more than 2 AC units
- System must be able to be installed without the need for the running of any new wires
Specifications and Requirements

- Must be able to provide 24V AC to control HVAC components (output)
- Wireless transmission of temperature and relative humidity data over a distance of at least 100 feet
- Measure indoor and outdoor temperature (± 0.5 °C) and relative humidity (± 5%) with specific accuracy
- Measure realistic outdoor temperature (-20 °F – 110 °F) and relative humidity (0% - 100%)
- Main Control Unit powered by existing 24V AC wall power (input)
- Total cost of the HVAC system $1500 or less for initial prototyping
Component Overview

- **Main Control Unit**
  - Main Microcontroller
  - 802.11b Wi-Fi Transceiver
  - 802.15.4 ZigBee Transceiver
  - Temperature / Relative Humidity Sensor
  - Control Relays

- **Outside Sensing Unit**
  - Secondary Microcontroller
  - 802.15.4 ZigBee Transceiver
  - Temperature / Relative Humidity Sensor

- **User Interface**
  - Evervision 7” LCD Touch Screen
  - SLCD5 Controller
Main Control Unit Components with Connection Types

- MRF 24WBOMA 802.11b RF Transceiver
- SHT21 Temperature and Relative Humidity Sensor
- MRF24J40MB ZigBee Wireless Transceiver
- dsPIC33FJ256GP710A Main Microcontroller
- Control Relays

Connections:
- SPI Interface
- I²C Interface
- Serial Connection
- One wire per relay

7" LCD Touch Screen Display
Main Control Unit (MCU)

- Houses several components such as the SHT21 sensor, dsPIC33FJ256GP710A main microcontroller, ZigBee MRF24J40MB wireless transceiver, and the MRF24WB0MA 802.11b wireless transceiver.
- Powered by a 24V AC common wire that is installed for a thermostat during the initial construction project.

Minimum, Maximum, and typical operating voltages for components associated with the MCU:

<table>
<thead>
<tr>
<th>Component</th>
<th>Min Operating Voltage (V)</th>
<th>Typical Operating Voltage (V)</th>
<th>Max Operating Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Microcontroller</td>
<td>3</td>
<td>N/A</td>
<td>3.6</td>
</tr>
<tr>
<td>Zigbee wireless chip</td>
<td>2.4</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>802.11b wireless chip</td>
<td>2.7</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Temperature and Relative Humidity sensor</td>
<td>2.1</td>
<td>3</td>
<td>3.6</td>
</tr>
<tr>
<td>LCD Touch Screen and Controller</td>
<td>5</td>
<td>N/A</td>
<td>12</td>
</tr>
</tbody>
</table>
## Comparison of Main Microcontroller Options

<table>
<thead>
<tr>
<th></th>
<th>dsPIC33FJ64GP206A</th>
<th>dsPIC33FJ256GP506A</th>
<th>dsPIC33FJ256GP710A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pins</td>
<td>64</td>
<td>64</td>
<td>100</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>64Kbyte</td>
<td>256kbyte</td>
<td>256Kbyte</td>
</tr>
<tr>
<td>ADC</td>
<td>1 ADC, 18 ch.</td>
<td>1 ADC, 18 ch.</td>
<td>2 ADC, 32 ch.</td>
</tr>
<tr>
<td>UART</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>SPI</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>I^2C</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>I/O Pins</td>
<td>53</td>
<td>53</td>
<td>85</td>
</tr>
</tbody>
</table>
Reasons for choosing dsPIC33FJ256GP710A

- C compiler optimized instruction set
- 256K bytes Flash memory
- 30K bytes RAM
- 85 Programmable I/O pins
- Supports 2 I²C modules
- Supports 2 UART modules
- The sponsors have stressed their desire to expand the capabilities of the system
Conversion from 24V AC to 3.3V DC

- First signal needs to be converted from AC to DC using full wave rectification
- The entire signal is the same polarity but the magnitude of the signal is still not constant to be considered DC.
- The signal is rippling in magnitude and in order to solve that problem a smoothing capacitor will be used
- Next step after using a smoothing capacitor is to use a voltage regulator
Remote Sensing Unit Components with Connection Types

Remote Sensing Unit

- SHT21
  Temperature and Relative Humidity Sensor

- PIC24F04KA201
  Secondary Microcontroller

- MRF24J40MB
  ZigBee Wireless Transceiver
Secondary Microcontroller
PIC24F04KA20I

- 20 Pins
- 4K bytes Program Memory
- SRAM 512 bytes
- 3 16-bit timers
- 1 UART
- 1 SPI
- I²C
Functions of Secondary Microcontroller

- Take input from Temperature and Relative Humidity Sensor (12 or 14 bits)
- Plug number into conversion formula
- Send information to Main Control Unit
Secondary Microcontroller Minimum Connections

- This is the PIC24F04KA201 and the minimum required connections as described in the data sheet.
Secondary Microcontroller with other external connections

- Secondary microcontroller with connections to ZigBee RF transceiver, temperature and humidity sensor, and female RJ11 port
## Comparison of LCD Touch Screens
(Sponsor Decision)

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Size of LCD Touch Screen</th>
<th>Controller Name</th>
<th>Controller Specs</th>
<th>Development Kit Price</th>
</tr>
</thead>
</table>
| Evervision   | 7 inches                 | SLCD5 Controller | - Power Supply Min 3.0 V to Max 3.6 V  
- 4 MB of flash memory  
- 16 bit color | $499 |
| Kyocera      | 5.7 inches               | SLCD+ controller | - Power Supply Min 3.0 V to Max 3.6 V  
- 4 MB of flash memory  
- 16 bit color | $499 |
| NEC          | 8.4 inches               | SLCD5 Controller | - Power Supply Min 3.0 V to Max 3.6 V  
- 4 MB of flash memory  
- 16 bit color | $799 |
Advantages of the 7” Evervision Development Kit

- SLCD5 controller was bundled with 7” Evervision LCD screen
- Evervision LCD screen utilizes 4 wire resistive touch technology.
- SLCD5 controller provides easy to use commands to implement bitmaps and macros
Commands Used in Development of User Interface

- **Xi 1 100 200**
  - Places bitmap index 1 at pixel location 100x200

- **Bd 1 x y “text” dx dy bmp1 bmp2**
  - Places a button at x y with text identifier “text” with text offset of dx dy, displays bitmap index of bmp1 in state 1 and bmp2 at state 2

- **T “text string” x y**
  - Places text at (x, y) in respect to the origin point

Display of various bitmaps and buttons
Format of LCD Touch Screen User Interface

Efficient HVAC Control and Feedback System
Max Energy Savings + Max Comfort

<table>
<thead>
<tr>
<th>SELECTION MENUS</th>
<th>ENERGY COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRESH AIR</td>
<td>MAXIMUM SAVINGS</td>
</tr>
<tr>
<td>AIR QUALITY</td>
<td></td>
</tr>
<tr>
<td>SETBACK SAVE</td>
<td></td>
</tr>
<tr>
<td>POWER COSTS</td>
<td></td>
</tr>
<tr>
<td>MOOD SCENTS</td>
<td></td>
</tr>
</tbody>
</table>

TEMPERATURE       HUMIDITY

COOLING

75                   55

HEATING

68                   45

UCF Group 6 Senior Design Project Fall 2010
SCLD5 Communication Setup

- Utilizes RS-232 for serial communication to host microcontroller
- COM0 is deemed the “Main” port and is connected to the embedded processor to control the display
- COM1 port or “Aux” is typically used to update the display of bitmaps and macros
- SCLD5 Communication Setup (2 RS232 Ports)
Wireless Protocols

- The protocols that we researched and considered were the ZigBee, Wi-Fi, and Bluetooth.
- The best communication interface for wireless in system communication was ZigBee.
- ZigBee was relatively simple and would be easily able to handle the readings we had to send.
- Good amount of sample code available.
- To enable mobile device connectivity we chose a Wi-Fi transceiver.
- Works well because there is normally not an Ethernet connection wired to the thermostat.
## Wireless Protocols

<table>
<thead>
<tr>
<th>Wireless Protocols</th>
<th>Bluetooth (Class 1)</th>
<th>ZigBee (802.15.4)</th>
<th>Wi-Fi® (802.11 b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Range (indoor):</td>
<td>~100 meter</td>
<td>10 – 75 meters</td>
<td>30 meters</td>
</tr>
<tr>
<td>Frequency Band:</td>
<td>2.4 GHz ISM band</td>
<td>2.4 GHz ISM band</td>
<td>2.4 GHz ISM band</td>
</tr>
<tr>
<td>Communication type:</td>
<td>WPANs</td>
<td>PANs</td>
<td>WLAN</td>
</tr>
<tr>
<td>Power required to operate:</td>
<td>100mW</td>
<td>1mW</td>
<td>100mW</td>
</tr>
<tr>
<td>Cost of implementation:</td>
<td>Low Cost</td>
<td>Low Cost</td>
<td>Medium Cost</td>
</tr>
<tr>
<td>Bandwidth:</td>
<td>1 Mbps</td>
<td>0.250 Mbps</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>Encrypted:</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Primary Use:</td>
<td>Data exchange over short distances</td>
<td>Small, low powered devices</td>
<td>Mobile Internet</td>
</tr>
</tbody>
</table>
802.15.4 MRF24J40MB RF Transceiver

- The sensors and secondary microcontrollers collect data which needs to be wirelessly sent to the main microcontroller.
- Our device that we wanted required low power consumption to increase battery life, low data rate and secure networking.
- MRF24J40MB is compatible with Microchip’s Microcontroller Families (PIC16F, PIC18F, PIC24F/H, dsPIC33).

<table>
<thead>
<tr>
<th>Key Features of the MRF24J40MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operates on ISM Band 2.405 – 2.475 GHz freq.</td>
</tr>
<tr>
<td>Supports ZigBee®, MiWi and MiWi P2p wireless protocols</td>
</tr>
<tr>
<td>Integrated PCB antenna</td>
</tr>
<tr>
<td>Operating voltage 2.4V – 3.6 V (3.3V typical)</td>
</tr>
<tr>
<td>Low current consumption</td>
</tr>
</tbody>
</table>
802.11 b MRF24WB0MA RF Transceiver

- This radio transceiver contains 36 pin surface mountable module that’s dimensions are 21 mm x 31 mm
- Requires low supply voltage: 2.7V – 3.6V (3.3 V is typical standard)
- Operates on the 2.4 – 2.483.5 GHz band, which is the 802.11 b protocol
- Designed to be used with Microchip’s TCP/IP software stack and microcontroller families
- The MRF24WB0MA module and a PIC microcontroller operating the TCP/IP stack will allow for implementation of a wireless web server
MRF24WB0MA  RF Transceiver (cont)

- This module interfaces to the microcontroller via a four-wire serial slave SPI interface, as well as the interrupt, hibernate, reset, power, and ground signals.
- Offers different modes of low current consumption depending upon what is recommended by the user.
- Receive (RX) mode only uses 85 mA, Transmit (TX) mode only uses 154 mA, Hibernate mode uses < 1 uA, while the Sleep mode uses 250 uA.

CS – SPI Chip Select input
SCK – clock
SDI, SDO – SPI data In and data out pins

MRF24WB0MA interface to microcontroller
The sensor we chose was the Sensirion SHT21 Humidity and Temperature Sensor

- Uses I\(^2\)C protocol to communicate with the microcontroller
- The SHT21 has a normal operating range from 20 °C to 100 °C (68 °F to 212 °F) at about 8% relative humidity and -20 °C to 60 °C (-4 °F to 140 °F) at 90% relative humidity
- Default resolution of 12 bits for relative humidity and 14 bits for temperature
I²C protocol and commands for SHT 21

- Uses two bidirectional lines for the I²C format: Serial Data Line (SDA), Serial Clock (SCL)
- Data can be sent across the SDA line after a start condition has been met
- The start condition is when the SDA line goes from a high to low while the SCL is high
- When the data is already done sending, a “stop condition” of the SDA going from a low to a high while the SCL is high occurs
- The I²C protocol once the start condition happens is followed up by a header made up of 7-bit device addresses and an SDA directional bit

Start and Stop Conditions for I²C protocol
Factors in Calculating Relative Humidity and Temperature Values

- Once the bits measurement is taken and the bits are transferred, it must be converted into a number that makes sense to the user
- Binary number must be converted to a decimal number (called $S_{RH}$ or $S_T$ for relative humidity and temperature)
- Once converted into decimal representation, the value must be plugged into a formula to get the final output

Formulas for Calculating Relative Humidity and Temperature Values for the User

\[ RH = -6 + 125 \times \left(\frac{S_{RH}}{2^{16}}\right) \rightarrow \text{units } \% \text{ RH} \]
\[ T = -46.85 + 175.72 \times \left(\frac{S_T}{2^{16}}\right) \rightarrow \text{units } ^\circ\text{C} \]
### Selected Battery

<table>
<thead>
<tr>
<th>Type</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| Alkaline (AA)          | - Long battery life  
                        - Has Energy Capacity of 2850 mAh              | - Drain rate affects the capacity              |
| Lithium - Ion          | - Produce nominally 3.6 to 3.7 V (very powerful)  
                        - Generates high current  
                        - Has an energy capacity of 2250 mAh  
                        - Relatively low self - discharge rate     | - Most expensive in cost                       |
| Nickel Cadmium (AA)    | - Decent discharge rate  
                        - Nominal cycle life of over 1,000 cycles     | - Short term battery life  
                        - Max current is approx 400 mA  
                        - Being prone to damage by overcharging     |
Software Overview

- C language used to code compiled with C30 compiler from Microchip
- LCD Interface programmed through microcontroller
- TCP/IP Stack and web server provided by Microchip
# HVAC Data Structures

<table>
<thead>
<tr>
<th>HVAC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Int : NumUnits</td>
<td></td>
</tr>
<tr>
<td>initHVAC(); processHVAC(); insertHVAC(HVAC_Unit)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HVAC_List</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HVACList : next</td>
<td></td>
</tr>
<tr>
<td>HVACList : prev</td>
<td></td>
</tr>
<tr>
<td>HVAC_Unit : unit</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HVAC_Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>uint : state</td>
<td></td>
</tr>
<tr>
<td>uint : heat</td>
<td></td>
</tr>
<tr>
<td>HVACDevice : Type</td>
<td></td>
</tr>
</tbody>
</table>
Design Issues

- Structs in C compiled with the C30 compiler are not word aligned and cause an address error trap when accessed.
- Delays caused by lack of library support for PCB components.
- Original 802.11 chips unavailable. Had to change to external antenna model.
Successes

- Uploading initial layout for the LCD screen in progress.
- One of two PCB designs is complete.
- Progressing through software development
- All main components have been ordered and received.
- Under budget
<table>
<thead>
<tr>
<th>Component Description</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7” Evervision LCD Development Kit</td>
<td>52-0102-12</td>
<td>Evervision Reach Technology</td>
<td>$499</td>
</tr>
<tr>
<td>MRF24J40MA PICtail Daughter Board</td>
<td>AC164136-4</td>
<td>Microchip</td>
<td>$60</td>
</tr>
<tr>
<td>MRF24J40MB PICtail Daughter Board</td>
<td>AC164134-2</td>
<td>Microchip</td>
<td>$30</td>
</tr>
<tr>
<td>Explorer 16 Kit</td>
<td>DV164037</td>
<td>Microchip</td>
<td>$299</td>
</tr>
<tr>
<td>Battery Holder</td>
<td>1024K-ND</td>
<td>Keystone Electronic</td>
<td>$7.59</td>
</tr>
<tr>
<td>PIC24F16KA102 Plug-in Module (PIM)</td>
<td>MA240017</td>
<td>Microchip</td>
<td>$25</td>
</tr>
<tr>
<td>MRF24J40MB Zigbee Wireless Module</td>
<td>MRF24J40MBT- I/RM</td>
<td>Microchip</td>
<td>$34.74</td>
</tr>
<tr>
<td>dsPIC33FJ256GP710A Main Microcontroller</td>
<td>DSPIC33FJ256GP710</td>
<td>Microchip</td>
<td>$17.08</td>
</tr>
<tr>
<td>PIC24F04KA201 Secondary Microcontroller</td>
<td>PIC24F0KA201-I/SO</td>
<td>Microchip</td>
<td>$1.72</td>
</tr>
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Grand Total: $974.13
Current Progress

Estimated Percentage Complete

- Overall: 45%
- Testing: 10%
- Prototyping: 20%
- Development: 30%
- Ordering: 90%
- Research: 95%
Questions