Affordable Home Automation For Improved Energy Efficiency

NEDC - Technical Paper (HS - Santa Teresa, Ganesh Pimpale)

Bruce Tom   Christopher Lee   Ganesh Pimpale   Marek Pinto

Santa Teresa High

SJSU Mesa Center

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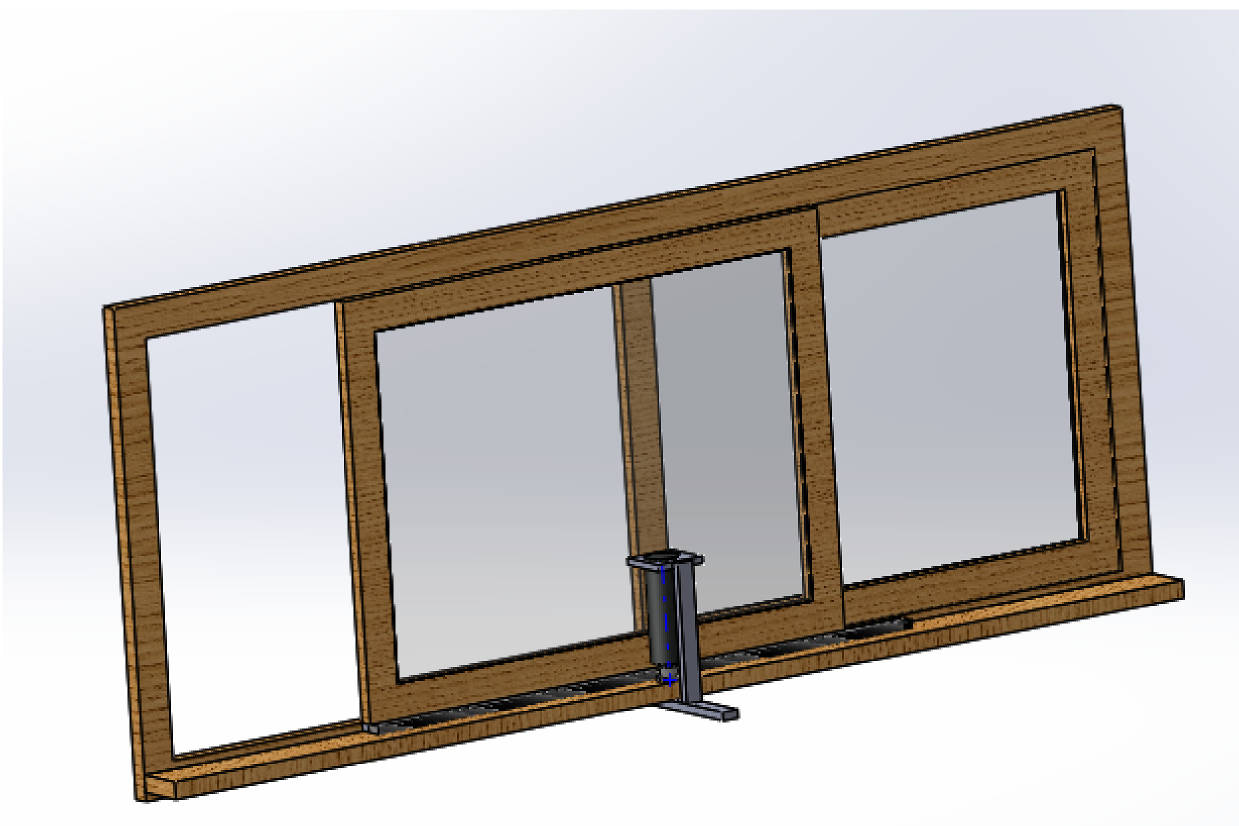


1. Problem Statement

According to the U.S. Energy Information Administration (EIA), 21% of all household energy usage in 2017 was directed towards space heating and cooling, for a stunning total of 298 billion kWh used in the United States alone. Additionally, the EPA's website states that approximately 1640 lbs of CO_2 are emitted per mWh. Therefore, nearly 500 billion lbs of CO_2 are emitted into the atmosphere each year from space heating and cooling alone.

Theenergy spent on space heating and cooling can easily be reduced with a simple energy-efficient way of heating and cooling - using windows. In hotter months, windows can be opened at night to cool down the house. In colder months, windows can be opened when the sun is out and hot to warm the house. This way, air conditioners need only be used for shorter periods of time.

However, the major constraint with using windows to regulate temperature is that windows have to be manually opened and closed at the optimal time to ensure that they properly cool down or heat up the house. Most importantly, many people are unable to open/close their windows at those times because they will be out at work during the day. Even during the night, people usually keep them open the whole night because they are sleeping.

Our clients need a system that will ensure that windows are opened/closed at the correct time based on the inside and outside temperatures. This will be automated but can be remotely controlled by our clients. It must also be connected to the A/C and heater to ensure that windows are not opened while the A/C or heater is running. Lastly, our product needs to be secure. If there is a remote way to open the windows, only the user should be able to open them, so that thieves cannot take advantage of the system.

2. Design Process

2.1: Inspiration

At the start of this project, we looked for common problems that faced us as well as people in our lives. Starting at our own households, we discovered that all four of our families described some sort of complaint with their high energy usage. We decided to focus our efforts on conserving energy in households, where space heating and cooling accounts for the most energy usage. Since temperature regulation requires the highest amount of energy in average households, we decided to design a product that would keep homes at a comfortable temperature while minimizing power consumption.

We then looked for alternative methods for regulating temperature. Some devices, such as fans and evaporative coolers use airflow to cool people down. The fan pushes air by spinning a rotor rapidly, and the evaporative cooler cools outside air and blows it inside. However, both of these still use quite a bit of energy over time. After interviewing our parents and researching more, we discovered that there is a more natural solution - windows. Outside temperatures cool down in the night and rise during the day. Therefore, temperature can be more or less regulated by opening the windows at different times in different seasons to either cool down or heat up the house. By doing this, space heating and cooling only needs to be used when opening windows will not regulate the temperature fully.

We decided that our clients need a product that can automatically open and close windows when it detects that doing so would be beneficial to regulating temperature in the house. While there are window openers, they cost over $1000 and are mostly designed for industrial settings. We need to design a product that is relatively inexpensive and easy to install so that a client can easily purchase it and quickly generate savings on their electricity bill to offset the cost of the product..

2.2: Formulating ideas

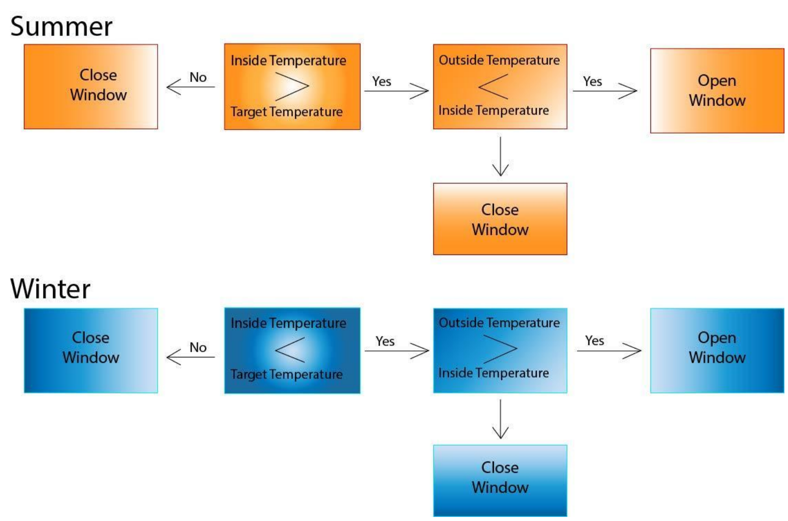
After we defined what our product should achieve based on what our clients need, we started to formulate ideas for how we could build our prototype. To build a mechanical window opener, we needed to create a mechanism to move the window. We brainstormed several different methods of opening windows, then decided which would work most effectively within our parameters.

Iterations for Mechanical Window Controller	
Design / Iteration	Pros and Cons
We first thought of attaching a chain below the window that would be connected to two motors on either side. As the two motors moved the chain, the window would move from one side of the frame to the other.	● Only works for horizontal windows. ● The window would have to sit on the chain. If the window was to be pushed, the chain would bend, moving the window. This would cause security problems as well as structural defects. ● Installation is potentially difficult. To apply this mechanism to a window, the user would have to replace one of the panes to a smaller one and would have to cut through the drywall.

Another option we considered was using a linear slide to move the window back and forth. This option had a lot of merit to it, as it would move smoothly back and forth and it would be compatible with vertical windows **and** horizontal windows, as opposed to just horizontal windows.	• The linear slide is difficult to install, probably requiring a specialist to come in and install it by replacing the entire window frameis very expensive and difficult to build in custom sizes. • It
Our last iteration was using a rack and pinion. A motor with a pinion can be attached to the base of the window and a rack to the window pane. As the motor moves, it moves the pinion, pushing the rack from side to side. Since the rack is attached to the window, it will move the window from side to side as well.	• Easy to install onto a window and just as strong as a normal window. • Even though traditional racks and pinions are expensive, we decided that we would use a 3D printer to print out our rack and pinion in a relatively inexpensive manner.

Combining the Hardware and Software:

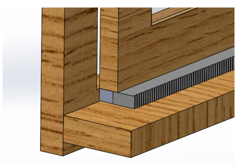
Our product will use an algorithm that compares the inside and outside temperature to decide whether or not opening the windows will help maintain a comfortable temperature.

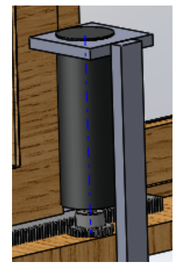


This program will also open windows slightly once a day to ensure that the house is properly aired out.

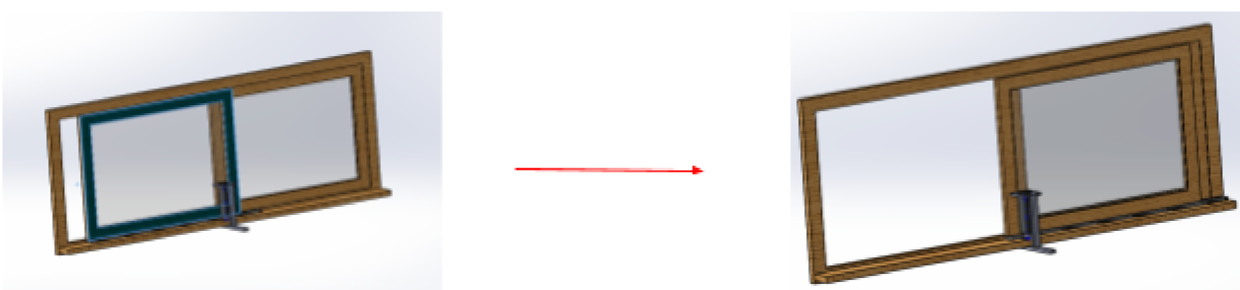
2.3: Prototyping

Window Movement:

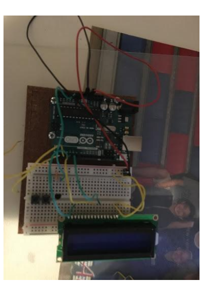


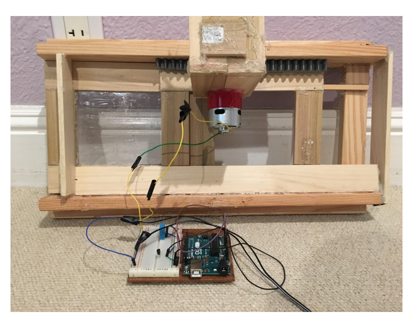


We tried experimentally to make the windows open and close using these methods. Based on our observations, and decided the rack and pinion system works best for horizontal sliding windows. The rack is attached directly to the moving pane of the window, and the pinion is attached directly to the motor. The motor is fixed to an area near the window. As the motor moves the pinion, it pulls the the rack to one side, pulling the window with it.



3. Results - final iteration of the prototype highlighting strengths





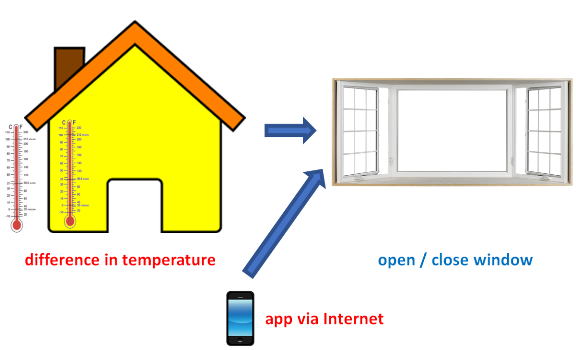
Our final prototype is a 18”x10” scale model of a window which uses our rack and pinion mechanism to push the window back and forth. This prototype serves to demonstrate the mechanical aspect of our product.

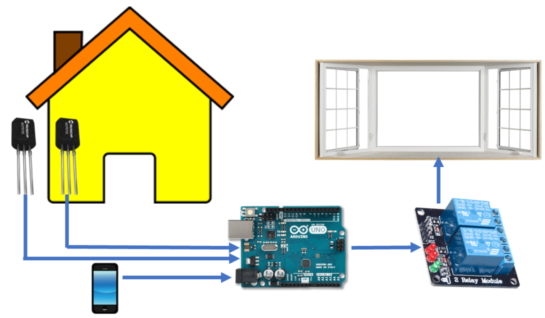
On the hardware side (as seen on the right), the rack is driven by an am-3775 motor attached to a 12-tooth pinion. The pinion drives a 21-tooth gear fastened to the window. The motor is powered with an adapter that converts 110 volts ac from an outlet into 12 volts dc.

The next prototype we created is a cardboard model of a house (as seen on the left) that serves to demonstrate how different windows in a house work together to regulate temperature in the house. This prototype uses 4-5 smaller 6” x 2” windows (as seen on the right), each of which are controlled by smaller dc motors. These motors will all connect to the Arduino through an h-bridge, which allows the Arduino to open and close the windows based on temperature readings coming from the tmp sensor and pre-programmed instructions.

4. Recommendations for further development or next steps for production

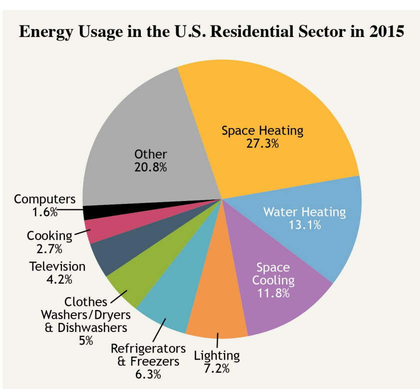
There are many different household elements that could be controlled by our affordable house automation. In the future, we plan on using our project to expand throughout the household and be able to control more than just windows. Window blinds, for example, can be moved using our system because blinds, like windows, play a huge role in the temperature control in a house or building. Because blinds are used to shade the light coming in from a window, it helps regulate temperature by controlling the amount of sunlight absorbed by the building. Another important addition is the user interface. In this application, the user should be able to open and close the windows and set their preferred temperature. They should also be able to set a certain temperature for a certain time. For example, if a client gets home at 8 PM, s/he can set the house to be a certain temperature at that time. Another part of the application is security. The user will be able to monitor what is near their window to make sure nothing is a threat and get notifications on when windows open and close.



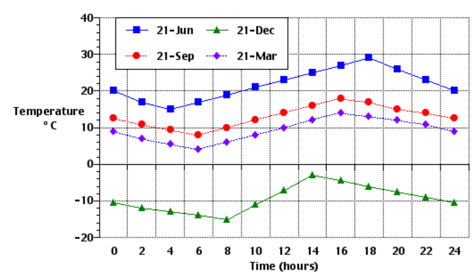


5. Data (Charts, Graphs, Tables) and any equations used

Energy usage in average households



Average temperature during different



seasons:

According to these graphs, the temperature is usually high between

11 AM-6PM during the summer. Thus, the windows will usually open around 6 PM and close around 11AM. As the seasons change, the windows will open during different periods of day, maintaining the correct temperature.

5.2 Math Concepts:

Throughout the design process, we used applied math and science to make decisions about our product. First, we needed to define a formula to find the correct motor. For this we used the torque formula, which states:

$T=Fr$ Or Torque = (Perpendicular Force) * (Vector from the axis to the point of force)

We calculated that we required 0.63 N-M (Newton Meters) to move our rack. This let us properly select the right motor to suit our needs..

The next concept we used was to calculate the temperature based on the voltage released by the tmp sensor. The Arduino takes the voltage from the tmp through an analog input pin. The input voltage is represented by a value ranging between 0 and 1023. We can convert this to the actual voltage by multiplying the number by 5/1024, because the tmp outputs a voltage of 0-5 volts proportional to the temperature. Then, we can convert the voltage to the temperature by subtracting 0.5 volts and multiplying by 100. This is because every 10 millivolts that the voltage changes is equivalent to 1 degree celsius change in temperature. We subtract 0.5 to offset the values because the tmp can also detect temperatures under 0 degrees. Therefore, we can calculate the temperature using the equation:

$$t(C^\circ) = 100(V-0.5),$$ Where V represents voltage.

6. Appendix

6.1.Arduino Code

```
//Add LCD library
#include < LiquidCrystal.h >
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
//Analog Input Reading coming from Temp Sensors
const int insideTemp = A0;
```

```
void setup() {
  //starts lcd library, inputs screen size
  lcd.begin(16, 2);
  //sets the three digital pins connected to the buttons
as input pins
```

```
const int outsideTemp = A1;
//Digital Input Readings coming from buttons adjusting
desired temperature
const int upButton = 2;
const int downButton = 3;
//On-Off Button
const int onOffButton = 4;
//Holds value of on-off switch
int onOffSwitchState = 0;
//Holds value of previous on-off switch state
int previousOnOffSwitchState = 0;
int on = 0;
float getInsideTemp() {
  //Reads TMP (Temperature Sensor) Reading
  int sensorVal = analogRead(insideTemp);
  //converts the TMP reading to actual voltage
  float voltage = (sensorVal / 1024.0) * 5.0;
  //converts voltage reading to temperature in celsius
  float temperature = (voltage - .5) * 100;
  //converts celsius to fahrenheit
  float tempF = (temperature * 1.8) + 32;
  //outputs temperature in fahrenheit to serial monitor
  return (tempF);
}
float getOutsideTemp() {
  //Reads TMP (Temperature Sensor) Reading
  int outsideVal = analogRead(outsideTemp);
  //converts the TMP reading to actual voltage
  float voltage1 = (outsideVal / 1024.0) * 5.0;
  //converts voltage reading to temperature in celsius
  float temperature1 = (voltage1 - .5) * 100;
  //converts celsius to fahrenheit
  float temp = (temperature1 * 1.8) + 32;
  //outputs temperature in fahrenheit to serial monitor
  return (temp);
  pinMode(upButton, INPUT);
  pinMode(downButton, INPUT);
  pinMode(onOffButton, INPUT);
 //write text to lcd
  lcd.print("Current");
  lcd.setCursor(0, 1);
  lcd.print("Desired");
}

void loop() {
  float insideTempF = getInsideTemp();
  float outsideTempF = getOutsideTemp();
  onOffSwitchState = digitalRead(onOffButton);
  delay(1);
  if (onOffSwitchState != previousOnOffSwitchState)
{
    if (onOffSwitchState == HIGH) {
      on = !on;
    }
  }
  if (on == 1) {
    lcd.setCursor(9, 0);
    lcd.print(insideTempF);
    lcd.setCursor(9, 1);
    lcd.print(insideTempF);
  }
  //Delays looping by 1 ms so that temperature sensor
has time to adjust
  previousOnOffSwitchState = onOffSwitchState;
  delay(1);
}
```

}

6.2. Budget Sheet

Item	**Price**	**Item**	**Price**	**Item**	**Price**
Arduino	$5.70	TMP (Temperature Sensor)	$0.82*2 = $1.64	Resistors	$0.99
DCr Motor	$1.51	Switch	$1.79	Breadboard	$1.53
Rack (3D Printed)	$20	Wire	$2.50	LCD Screen	$2.24
Pinion/Gear(3D Printed)	$20	9V Battery	$5.00	Buttons	$0.38
Total	$63.28				

7. Bibliography

- Anderberg, Jeremy. "How to Keep Your House Cool (Without Cranking the A/C)." N.p., 1 June 2016.Web.https://www.artofmanliness.com/2016/06/01/how-to-keep-your-house-cool-without-cranking-the-ac/
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