8.0 ENERGY MANAGEMENT SYSTEM NARRATIVES AND DESIGN

8.1 Energy Management System Overview

Home control systems have been implemented to modern houses with a goal to make occupants’ life easier, simpler, safer, more fun and comfortable. However, a home control system can offer more than the aforementioned advantages. The occupant of a house can manage the amount of energy that is being consumed by proper monitoring of critical parameters (e.g., temperature, humidity) and control of a series of functions (e.g., HVAC, lighting, ventilation) necessary in everyday life use. Automating the house operations reduces the amount of manual labor, improve energy performance and produce consistent results. Hence, the goal of the Energy Management Systems is to monitor the heating, ventilation, cooling, lighting, and electric loads in the house and through automated control over these systems to reduce energy consumption while maintaining the full functionality and comfort in the house. The monitoring system is used to acquire and save the data. The control actions are performed by the main control unit without the need of the continuous user input. Within the process all applicable local, state and national codes that regulate the installation and operation of the control system are followed, this minimizes the risk of potential safety problems. Safety is an important factor in the design as well as the implementation of the control process and care is applied. Applicable sections will be followed. This includes the National Fire Protection Association (NFPA) and the codes of the National Electrical Manufacturers Association (NEMA). The automated control system is also approved and register with testing laboratories like Underwriters Laboratories (UL). Through the Energy Management System the occupant will be able to control lights, HVAC, appliances, windows, blinds, and irrigation.

8.2 System Description

8.2.1 Monitoring System

The development of a home management system has emerged and developed as a new method that can aid in the conservation of energy. The Solar Roof Pod has a unique monitoring platform that has the potential of data and through proper processing and algorithms can demonstrate high energy efficient buildings. Noveda Technologies’ SunFlow Monitor and Energy-Flow Monitor are the main components that are used to collect and display real-time energy production and generation. In addition, the Carbon Footprint Monitor is a powerful software application, which delivers detailed information of carbon emissions reduction initiatives. Multiple sensors and control units provide accurate analysis of energy generation and consumption.
The following sections describe the functionality of the Noveda monitoring system in more detail and in particular as it pertain to the monitoring of energy generation and consumption, the collection and logging of data for better understanding of the house requirements, needs and plan of action, consumption of water, and tracking of the carbon footprint of the house.

8.2.1.1 Energy Generation
The Solar Roof Pod uses Noveda Technologies’ SunFlow Monitor to present energy generation and consumption levels. The monitoring platform displays real-time diagnostics of system’s performance in a dynamic user-friendly graphical interface. The SunFlow Monitor combines detailed analysis of the energy production in a flexible data export to demonstrate efficiency of the system (Fig 2). It highlights the different parameter monitoring as well as the different display option for a better understanding of the Solar Roof Pod energy requirements and potential energy savings strategies.
The Sun Flow Monitor uses a robust microcontroller unit (MCU) to evaluate various collected data through gateways. A variety of sensors collect data, which are then stored and processed to evaluate energy production and consumption from the micro-inverters and the grid. The data is received through terminal blocks and processed using Noveda’s TAC controller. The SunFlow Monitor displays detailed information and complete real-time energy data from the collected energy generation data, thus providing the occupant with detail real-time information of the building's energy performance.

8.2.1.2 Energy Consumption
In addition to the energy generation data, Noveda Technologies’ EnergyFlow Monitor provides real-time monitoring and management resources for optimizing energy production and the home’s performance. The Solar Roof Pod precisely tracks and analyzes specific Solar Roof Pod’s components. The system has the ability to decrease energy consumption and lower energy costs by pin-pointing to the occupant the operations that consume the most and in particular what habits of the occupant can be corrected to provide lower energy consumption. Hence, the EnergyFlow Monitor will be able to educate and train the homeowners to developing greener habits.

The monitoring platform will send immediate notifications through text messaging and website. These notifications depend on user-defined parameters.
The EnergyFlow Monitor uses a microcontroller unit (MCU) to accurately analyze and optimize energy consumption through the entire house. Current transformers collect energy consumption data stored in a data logger, SATEC BFM 136. The EnergyFlow Monitor’s MCU collects and processes information from the sensor units and displays detailed graphical diagrams that show the energy consumption trends in the house. The user can select different displays that show the energy consumption at different dates and/or times, and can pinpoint on specific dates and/or home operations.

The proper collection of the data and associated processing is accomplished through an automatic data logger, the SATEC Branch Feeder Monitor (BFM136). The SATEC BFM collects energy data from several electrical loads and processed data for the Noveda controller. Automated energy metering allows owners to understand the home’s detailed energy consumption in every load of the Solar Roof Pod.

The meter can monitor energy demand using several phase channels. BFM136 uses 12 three-phase or 36 single-phase channels to collect energy reading and multi-tariff (TOU) data. The Solar Roof Pod processes events and data logging information for accurate metering. The EnergyFlow Monitor uses SATEC BFM136 to process data for web-based energy management display. The compact design allows occupants to access information about several channels of energy consumption reading collected throughout the house. The purpose of installing a wide input data logger is to make the system capable to sub metering consumption from every load in the house, as for example consumption from the lights in every room, and/or appliances.
8.2.1.3 Water Consumption
Water consumption is a key feature that our monitoring system will use to provide energy-efficiency and a greener environment. The Solar Roof Pod integrates several water consumption and leakage detectors into the water supply system, such as the kitchen, bathroom, and mechanical room. The water leakage detectors detect possible failures in the piping system and hence identify water wastage and aid in prevention of it. Occupants are notified of various water causalities, such as high water pressure and corrosion in plumbing. The monitoring platform alerts users from a web-based energy management site and sends text messages via cell phone. Overall the Solar Roof Pod monitors water consumption and leakages, which aid homeowners, develop greener habits. Fig. 5 shows the water consumption display of our monitoring system.

![Figure 5 - Sample water consumption screen shot display](image)

8.2.1.4 Carbon Footprint
Besides collecting energy generation and consumption data, the Solar Roof Pod displays real-time tracking and reduction of environment conditions. Noveda Technologies’ Carbon Footprint Monitor can display accurate energy efficiency data and carbon footprint reduction accomplishment. The customizable graphical display allows homeowners to view the house’s greenhouse gases and carbon emissions that were avoided (Fig. 6). The Solar Roof pod integrates sustainability initiatives by providing carbon footprint resources and environmental impact in an easy to understand manner. The Carbon Footprint Monitor can aid homeowners to make greener decisions about future carbon emissions and CO₂ production.
8.2.2 Control System

The Control System is interfaced with the monitoring system and is responsible for appropriate actions in regards to the operation of lights, HVAC, appliances etc. Hence, the system operation is critical in achieving our goal of reduced power consumption. It consists of high-level sensor fidelity, energy and water efficiency and an innovative home security.

The homeowner has full access control of the control system of the Solar Roof Pod through three different access points:

1. In-house control panel
2. Mobile phone
3. Personal computer

The Control System has several different capabilities. First, it alerts the homeowner if the house is consuming increased levels of energy. Second, it can take an automatic action based on user-defined parameters. Alternatively, it can allow the user to take over and apply manual actions depending on the situation. The cell phone interface is made via text messaging; the homeowner sends text-based commands to request up-to-date information from the home conditions and energy generation/consumption, and receives the requested information via text messages. The idea of sending simple text messages over a phone application is powerful as it is not confined in the use of sophisticated cell phones (smart phones), but also it can be used with any type of cell phone. The personal computer interface is made via internet; the home owner can check the status of the house and can send commands from any personal computer with internet access by interacting into a dedicated website. The control panel will use a Zigbee and/or Bacnet protocol. The homeowner can change any home settings from one room to another room just by a touch of a button. The Energy Management System controls the home’s real time energy, water consumption, humidity, and indoor temperature.

The best way to explain our design approach is by using a block diagram that shows how the components are connected. Fig. 7 shows the overall vision of the control system for the Solar Roof Pod which we consider quite unique and looking forward to demonstrate to the public and judges during the competition.

**Figure 6 - Sample Carbon footprint screen shot display**
The device takes action to comply with user’s desire while saving energy. The wide range use of sensors is a key element to the control system. We plan to have sensors for:

1. Occupancy/Vacancy
2. Light
3. Temperature
4. Humidity
5. Water
6. Air flow
7. Wattage consumption for the appliances.

Each type of sensor has a specific function in the house. For example, motion sensors control indoor and outdoor lighting and also provide intrusion alert, in other words the sensors can be used as a security system too. The lights can also be controlled with dimmer switches, so the level of light can be adjusted according to the occasion and according to recommended levels from the standards. Light sensors will control the automatic blinds and/or the lights. By implementing these technologies we will get as much as natural light possible and we will be able to have a good balance of artificial (when needed) and natural lighting. Temperature and humidity sensors communicate data to the controller and take action over the HVAC, as well as the automated operable windows. Another part of our innovation system is to have a smart irrigation system. The moisture of the soil in the pots will be monitored via moisture sensors and depending on preset seasonal settings the controller will allow the proper irrigation strategy. Finally, in compliance with code standards, the Solar Roof Pod will have smoke detectors.

One of the most attractive features about the energy management system is the Graphical User Interface (GUI) that has been created by our team from City College of New York. The system will interface the control and monitoring functionalities under the same software platform. This is a unique design which is ease of use for users to monitor and control the complex systems that has been implemented. Having this option, the homeowner can be anywhere and be able to check the conditions and/or status of the house by just accessing from a
mobile phone and/or personal computer that supports the Solar Roof Pod application. Fig. 8 shows the main window display, where each icon is associated with one monitoring and/or control command.

![Main Window GUI display.](image)

Figure 8 – Main Window GUI display.

Under user interface (UI) the homeowner would have the option to schedule the HVAC, lights, and either auto or manual control for windows and blinds. Fig. 9 visually shows the procedure. The user decides the mode which is described in Fig. 9a. For example if HVAC is in power mode, the controller will continue to use ventilation for heating and cooling without any attenuation from the set point temperature. Ventilation through windows is not used. Instead, the Controller always uses the HVAC system for heating and cooling. This mode requires the most energy. If HVAC is in Eco mode, it will be put on standby, where temperatures are allowed to deviate from the set point. For example, HVAC will keep a 5°F deviation from the median [73 F]) which leads to [68, 78]. Eco mode saves energy by sacrificing comfort level. By default the HVAC is in auto. Auto mode simply follows the HVAC algorithm. This mode differs from eco because priority is still given for comfort level of temperature to be with 71 – 76 range and humidity to be less than 60%.

Advance mode is password protected because it would allow technicians manual control of certain HVAC pipe systems. When non-experienced user changes values, it can disturb the entire HVAC system. Custom mode is where the homeowner can set certain days to have certain actions performed from the HVAC and also for lights. For example, if the homeowner has guests coming over and they prefer warmer temperature, the owner can set higher temp settings for the weekend and select back to previous mode under options. The HVAC will return to the previous mode at the end of the weekend (midnight on Sunday). For lights, if the homeowner wants to keep the lights in certain areas “on” during night he has the option to do so. Furthermore, the homeowner is able to schedule the lights to turn on at a specified time if he or she is away from the house. This feature could be used for security purposes. The windows and blinds can be set to be manually controlled instead of having the algorithms open and close them. The display image for the in-house touch screen panel is shown in Fig. 9b, which shows a top view of the entire house and provides access to each component, its settings and the energy performance parameters. In this particular figure, it shows the performance of the house at outside cold temperature, cloudy conditions, low solar radiation, and low humidity. It can be seen that according to the-
se readings the house starts to heating up, and since cloudy conditions does not allow natural light coming to the house, the necessity of using artificial lights is crucial for visual comfort when the user is present in the house. The display has soft (touch-screen) buttons, where the homeowner can choose to check the lights, windows, HVAC, blinds and irrigation to have a better perspective of the status of each system separately.
Figure 9 - (a) Overview behavior of the Control System schedule; (b) Roof Pod Graphical User Interface

The distribution of the sensors around the house is shown in Fig. 10. The types of sensors and switches are divided into groups, identified by five colors. The blue represents occupancy/vacancy sensors, orange represents daylight sensors, purple represents the temperature/humidity temperature, brown represents the CO$_2$ sensors, red represents smoke detectors, and grey the fire voice alarms and green represents manual/dimmer switch for the lights. The sensors were placed based on two conditions:

(a) Dimensions of where lights are placed in the room and
(b) Incoming natural light.

Note that not all the lights in the room are controlled. Some parts of the windows consist of a daylight sensor occupying the ceiling. This also applies to the entrance and exit since they have glass within them where light can pass through. It can be seen that from Fig. 10 shows the house schematic and the rooms and also the position and type of sensor. There are eight daylight sensors, six occupancy/vacancy sensors, and eight manual switches/dimmers around the nine windows marked in red and including entrance/exit marked in white.
Figure 10 - Sensor Location Configuration
8.2.2.1 Lights Control
Lighting accounts as one of the major contributors of energy consumption in residential buildings. By integrating a smart lighting system into the house, the electrical consumption and consequently the electric bills can be reduced from 60% to 40% according to ASHRAE. In general, the lighting control system consists of a device that controls electric lighting alone, or as part of a daylight harvesting system for public, commercial, industrial or residential buildings and facilities. They are often part of sustainable architecture and lighting design for integrated green building energy conservation programs. In our lighting design, we utilize a control system as an interface to interact with the sensors provided by Lutron in order to produce automatic lighting system.

Incorporating sensors throughout the house reduces the operating hours of the lighting, hence reducing the electric consumption. Such sensors include Lutron’s occupancy/vacancy sensors as well as daylight sensors. These sensors are wireless in order to promote wireless technology and show its reliability. The sensors communicate to the smart switches via radio frequency (RF). The combination of sensors and dimmers can potentially reduce energy consumption. In addition, the sensors and in particular daylight sensors allow for efficient use of the natural daylight, which helps accomplish appropriate lighting levels in the indoors environment. Hence natural and artificial lighting operate in complimentary fashion. The amount of energy that the dimmers conserve is proportional to the light level, such that 50% dimmer uses only 60% of the energy, conserving 40%.

The living space is composed of the entrance/exit, hallways, kitchen, bathroom, living room and mechanical room. Each living space consists of certain amount of lights and contains one occupancy/vacancy sensor. The Solar Roof Pod has been design to have nine windows. There are either two or three windows from each axis point north, east, south, and west. The day light sensors are placed between windows. If two or more windows are closely apart at each side of the building only one-day light sensor is placed. If the distance exceeds more than 3 feet, then each window has its own day light sensor within that axis. Each set of lights shares one manual switch/dimmer. If the day light sensors force the artificial lighting to be dimmed excessively, the user can take over the control and based on preference and comfort adjust the lighting either with the manual switch/dimmer or by using the touch screen panel. A more detail status of the lights in every room is presented through a graphical user interface (GUI) in the touch screen panel, as shown in Fig. 11. This GUI presents the status (e.g., level of dimming) of each light in the Solar Roof Pod.

![Figure 11 - The light automation status and control GUI.](image-url)
The control of the light is done through the collection of associated data from the lighting and occupancy sensors. An algorithm has been developed to allow for an efficient control of lights. The algorithm first determines if motion is detected within the volume of space it occupies. If such movement is detected, then the data will go straight to the controller and, in response, it will send a signal in order to turn on the lights. If natural light is detected via the day light sensors then it will prompt the lights to dim. And if nothing is detected then no lights will be turned on.

Fig 12 - Lights Algorithms Flowcharts

8.2.2.2 HVAC
The HVAC system is a critical one because it consumes the largest amount of energy. It is controlled automatically so that energy savings can be accomplished. Taking into consideration that cooling or heating does not need to be fully “on” in every room or zone in the house energy can be conserved. For details on the input/output behavior, information on the control strategy to achieve part load heating, and dynamic control of fluid flow, please visit the HVAC control section. The main controller can take decisions on the HVAC without the user’s input. The controller collects information from the CO₂, humidity, and temperature sensors in the rooms and temperature in domestic hot water and solar thermal tank to make decisions. The HVAC control requires multiple inputs and outputs. The outputs are either the analog or digital signals the controller sends to regulate a particular component in the HVAC system.

For the competition, the temperature requirement for the indoor temperature is in the [71-76 F] range. The target humidity level is less than 60%. To save energy, the controller will enable natural ventilation if conditions permit. Otherwise it will send a signal to operate the active thermally driven HVAC. Manual control for setting temperature and humidity values will be an option through the in house control panel. To illustrate certain conditions for the HVAC, a graphical user interface is shown in the Fig. 13. The GUI represents a state when the house is being cooled. The temperature is 78 F therefore cold air is pumped throughout the house to lower the temperature. The ACS chiller is used to pump cold air to the fan coils through which air distributes throughout the house. Also the GUI shows that the collector temperature is greater than the PCM tank temperature.
Hence GUI shows the “thermal pump on” state. For more detail on the image please visit the HVAC narrative section 6.7.

**Figure 13 - HVAC GUI**

The details of the algorithm developed to control the HVAC is shown if Fig. 14. In the algorithm flowchart the different decision steps are highlighted.

**Figure 14 - HVAC Algorithms Flowcharts**
8.2.2.3 Blinds
The idea of implementing automated blinds, as one of the features of the house will greatly improve the energy savings of the Solar Roof Pod because it leverages the natural light as well as thermal energy to balance the artificial lighting as well as internal temperature. The automated blinds system consists of several components. First there is a solar radiometer, which will be mounted, on the roof. This sensor detects the amount of natural light in the vicinity, determines the profile angle of the sun and compares those readings with a prebuilt light analysis database. Then the system compares the measurements and the stored data and performs different functions based on preset decision points. The control system adjusts the blind positions on the window automatically by monitoring the real-time sky conditions over the course over the year. Fig. 15 shows the comparison between the two input data.

Figure 15 - Solar Radiation Curve. Theoretical and Measured Values

The unit allows both manual and automatic control for the blind system. The benefits of having automated blinds is that maximizes or optimizes the amount of natural light and view thru the window by appropriate control of the blinds tilt angle as well as elevation of the blind system in the window opening. During sunny days the blinds will be completely down and will only be opening and closing. During cloudy days the blinds will move vertically to up and down position and keep the blinds will remain in the open position. For example during the warm and sunny summer season, blinds can be adjusted to block direct radiation in the interior of the room, especially when the occupants are not present. Hence, blinds functionality provides lower heating load and hence the HVAC needs are reduced. On the other hand, during the winter and depending on the sky conditions, the system can adjust the blinds to allow direct or indirect sunlight to penetrate in the building and hence help keep the interior at a higher temperature and reduce the HVAC needs. Fig. 16 shows a detailed graphical interface for the 3 windows with automated blinds that will be implemented as well as the position in the house.
Figure 16 - Automated Blinds GUI

Note that by having automated blinds we can save energy by balancing natural and artificial lighting (e.g., dimming the lights as needed) and adjusting the HVAC at a comfortable level automatically. An algorithm flowchart has been created to illustrate certain conditions that need to meet in order to operate the blinds. The blinds will work as a separate system and based on the output, the other sub systems controls will accommodate their behavior. During the entire competition the operation of this system will be shown to the public. It has been created an algorithm flowchart to illustrate certain conditions that need to meet in order to operate the blinds.

![Blinds Algorithm Flowchart](image)

8.2.2.4 Motorized Windows

The automated motorized window is an innovative idea. The main purpose of having motorized windows is for fresh air ventilation. This automated feature will also have an impact in the operation of the HVAC system. The idea for this house is to use as much as natural resources as possible. By taking advantage of the natural air...
energy savings can be accomplished by turning off the HVAC when the outside conditions are appropriate. In Fig. 18 the concept of natural air ventilation is shown.

![Window Ventilation Design](image)

**Figure 18 - Window Ventilation Design.**

To have successful window automation, information from the inside and outside is needed. For this automation part we will be using carbon dioxide detectors in every face of the house to monitor the outdoors air quality. Temperature and humidity sensors for the inside conditions and a weather station for ambient outside conditions will also be used. Another type of sensor that is crucial is the wind sensor because this will determine whether or not wind conditions are favorable for the ventilation system performance. Air circulation through windows becomes useful when temperature in the house is greater than 72 degrees and humidity is below 60 percent. Figures show temperature outside to be less than 72 degrees and the humidity to be less than 60 percent and thus, through the simulation, windows can be opened between 11 am through 5 pm (Fig. 19).
The windows will not open fully for safety issues (child safety) but rather until a certain level. In Fig. 20 a graphical user interface for the specific behavior of each automated window is depicted. It displays four (4) operable windows and the current status of each one. Fig. 21 depicts the flowchart of the algorithm, which will operate under certain conditions for the automated windows.

Figure 20 - Automated Windows GUI
8.2.2.5 Irrigation

The irrigation system is an integrated part of a holistic sustainable building. It is an important aspect because it confronts important issues an urban environment faces, that are storm water runoff and grey-water reuse. The idea is to be able to have full control of the water within our footprint. The main task is to reuse water for watering the plants in the outside patio area, through an automated watering system.

The system has two parts that work together, rain water and grey water (Fig. 22). The rainwater is collected from the roof through two drains that lead to a bladder that stores the water underneath the southern part of the deck. The rainwater is collected from the roof through two drains that lead to a 3.5’ x 3.5’ x 8” 100 gallon bladder that stores the water underneath the southern part of the deck. The black water is collected through a series of drains in the house, such as dish washer, kitchen sink, bathroom sink, shower and clothes washer then is stored in a bladder parallel to the rain water bladder under the deck. A filter is located at the outtake of the grey water bladder. Hence the grey water quality is significantly improved and is appropriate for use in irrigation of the outside plants.

The smart system for irrigation is composed of sensors and is programmed to accommodate different water requirements and conditions. The lead in the chain of triggers is the moisture sensors. They will be programmed to be stimulated once the plants are in need of at least one pint of water to reach their optimal moisture level. The smart irrigation has two water sensors located in both rain and grey water bladders. Each sensor first reads the water level and communicates it to the control system. If the water level in the rainwater tank is at least 1 inch (12.5 gallons) it will open the valve and pump for one hour. On the other hand, if it is not at the appropriate water level, the system moves on to the grey-water level sensor. If there is a sufficient level of water in this tank the valve opens and the pump operates. The grey water will pass through the filter before reaching the plants. At the event that the grey water is at an inefficient level an alert is issued that notifies the resident about...
The control system then issues suggestions for the amount of grey water generation for different tasks in the house that could alleviate this problem. These suggestions will be based on historical data from the home. For example, the system may suggest for operation of the washing machine at an earlier time than usual so that the necessary amount of grey water is generated. Fig. 23 shows the flowchart of the algorithm developed for the irrigation.

![Irrigation GUI](image)

**Figure 22 - Irrigation GUI**
Fig 23 - Irrigation Algorithms Flowcharts