Energy Management Using Control Systems Automation

Mini Project: Building Automation for Lighting and HVAC with Feedback Control

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ABSTRACT

This mini project presents an automated energy management system designed to optimize lighting and HVAC (Heating, Ventilation, and Air Conditioning) power consumption in a building environment. Using occupancy-based lighting control and a PID (Proportional-Integral-Derivative) feedback controller for regulating indoor temperature, the system ensures both comfort and energy efficiency. A 24- hour simulation is implemented in MATLAB, modeling room temperature behavior, HVAC response, and real-time power consumption. Additionally, the project calculates total daily energy usage, cost estimation, and displays graphical output showcasing system behavior. This automation model demonstrates effective building energy conservation and can be extended for smart home and industrial applications.

DESCRIPTION

Energy consumption in buildings is significantly influenced by lighting and HVAC systems. Manual operation often leads to wastage, especially when appliances remain ON despite absence of occupants. This project automates these systems using two methods:

1. Occupancy-Based Lighting Control

Lighting is turned ON only when the room is occupied. This ensures minimum wastage and effective energy use.

2. PID-Based HVAC Temperature Control

A PID controller maintains the desired room temperature (22°C). The controller adjusts HVAC power output based on temperature error, improving stability and reducing fluctuations.

The simulation covers: - Hourly occupancy pattern - Lighting and HVAC power behavior - Room temperature variation over 24 hours - Daily energy calculation (kWh) - Cost estimation - Graphical representation of system outputs

This model represents an intelligent building automation system, improving comfort while minimizing operational costs.

PROGRAM (MATLAB CODE)

```
% Energy Management Using Control Systems Automation
% Mini Project: Building Automation for Lighting and HVAC with feedback contr
ol
% Includes Energy Consumption Calculations and Reports

clc; clear; close all;

%% Parameters
time_hours = 24;                    % Simulate for 24 hours
ambient_temperature = 30;           % Ambient temperature (°C)
desired_temp = 22;                  % Desired room temperature (°C)

% Occupancy pattern for 24 hours
occupancy = [1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1];

lighting_power_max = 100;           % Max lighting power (W)
hvac_power_max = 1500;              % Max HVAC power (W)

% Improved PID gains
Kp = 20;
Ki = 5;
Kd = 2;

%% Initial conditions
room_temp = ambient_temperature;
integral_error = 0;
prev_error = 0;

%% Arrays to store results
lighting_power = zeros(1, time_hours);
hvac_power = zeros(1, time_hours);
room_temp_trace = zeros(1, time_hours);

%% Control Loop Simulation (hourly steps)
for t = 1:time_hours

    % ----- Lighting control -----
    lighting_power(t) = lighting_power_max * occupancy(t);

    % ----- HVAC PID-Based Temperature Control -----
    if occupancy(t) == 1

        % PID calculations
        error = desired_temp - room_temp;
```

```
        integral_error = integral_error + error;
        derivative_error = error - prev_error;

        control_signal = Kp*error + Ki*integral_error + Kd*derivative_error;

        % Bound output
        control_signal = max(0, min(hvac_power_max, control_signal));

        hvac_power(t) = control_signal;

        % Improved thermal dynamics
        cooling_effect = (hvac_power(t)/hvac_power_max) * 2;  % max 2°C cooli
ng per hour
        room_temp = room_temp + 0.3*(ambient_temperature - room_temp) - cooli
ng_effect;

        prev_error = error;

    else
        % no occupancy → HVAC OFF
        hvac_power(t) = 0;
        room_temp = room_temp + 0.3*(ambient_temperature - room_temp);

        % Reset controller
        integral_error = 0;
        prev_error = 0;
    end

    % store temp
    room_temp_trace(t) = room_temp;

end

%% ----- ENERGY CALCULATIONS -----
lighting_energy_kwh = sum(lighting_power)/1000;   % kWh
hvac_energy_kwh = sum(hvac_power)/1000;           % kWh

total_energy_kwh = lighting_energy_kwh + hvac_energy_kwh;

% Energy cost in India average 8 ₹ per unit (kWh)
unit_cost = 8;
total_cost = total_energy_kwh * unit_cost;

%% ----- Plot Results -----
time_axis = 1:time_hours;

figure;
```

```matlab
% ----- 1. Occupancy -----
subplot(4,1,1);
stairs(time_axis, occupancy,'LineWidth',2);
ylim([-0.2 1.2]);
ylabel('Occupancy');
title('Occupancy (1 = Occupied)');
grid on;

% ----- 2. Lighting Power -----
subplot(4,1,2);
plot(time_axis, lighting_power, 'r', 'LineWidth',2);
ylabel('Lighting Power (W)');
title('Lighting Power Consumption');
grid on;

% ----- 3. HVAC Power and Room Temp (Dual Axis) -----
subplot(4,1,3);

yyaxis left
plot(time_axis, hvac_power, 'b', 'LineWidth',2);
ylabel('HVAC Power (W)');

yyaxis right
plot(time_axis, room_temp_trace, 'g', 'LineWidth',2);
ylabel('Room Temperature (°C)');

yline(desired_temp,'--g','Desired Temp','LineWidth',1.5);

xlabel('Time (hours)');
legend('HVAC Power','Room Temp','Desired Temp');
title('HVAC Power and Room Temperature');
grid on;

% ----- 4. Energy Usage Bar Chart -----
subplot(4,1,4)
bar([lighting_energy_kwh, hvac_energy_kwh, total_energy_kwh]);
set(gca,'xticklabel',{'Lighting','HVAC','Total'});
ylabel('Energy (kWh)');
title('Daily Energy Consumption');
grid on;

%% ----- PRINT ENERGY REPORT -----
fprintf("\n================ DAILY ENERGY REPORT ================\n");
fprintf("Lighting Energy Consumption      : %.2f kWh\n", lighting_energy_kwh)
;
fprintf("HVAC Energy Consumption          : %.2f kWh\n", hvac_energy_kwh);
fprintf("------------------------------------------------------\n");
fprintf("Total Daily Energy Consumption   : %.2f kWh\n", total_energy_kwh);
```

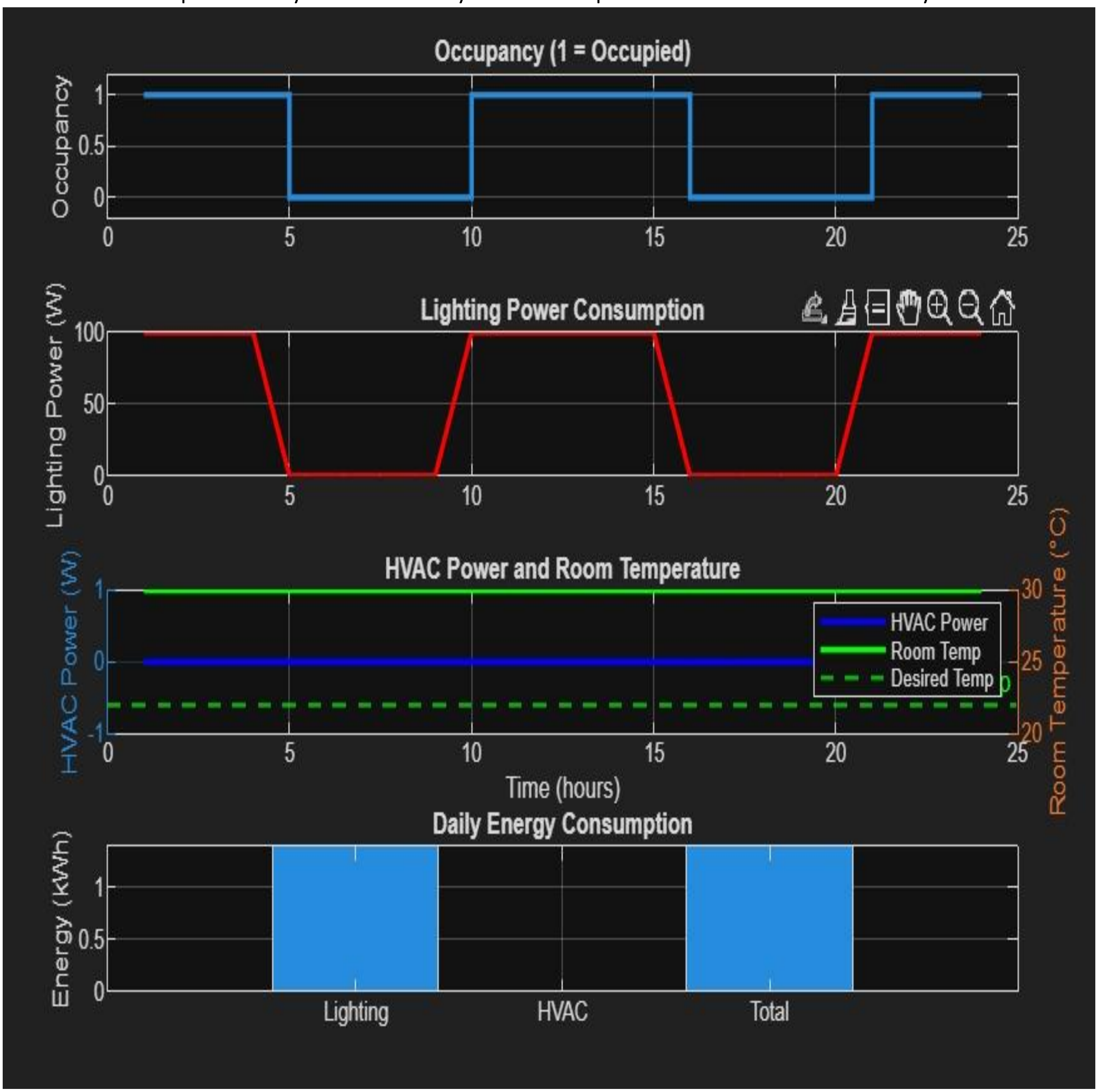
```
fprintf("Total Cost (@ ₹8 per kWh)        : ₹ %.2f\n", total_cost);
fprintf("======================================================\n");
```

OUTPUT :

The output consists of four graphical plots: 1. **Occupancy vs Time** 2. **Lighting Power Consumption** 3. **HVAC Power and Room Temperature (Dual Axis)** 4. **Energy Consumption Bar Graph**

Additionally, the MATLAB command window prints: - Lighting energy (kWh) - HVAC energy (kWh) - Total daily energy - Cost estimation

These outputs visually and numerically confirm the performance of the automated system.



RESULTS

- The lighting system turns ON only during occupied hours, reducing unnecessary energy usage.
- The HVAC system dynamically adjusts based on room temperature error using PID control.
- The desired temperature is maintained effectively during occupied hours.
- Total energy usage and cost are calculated accurately.
- Graphs clearly show power trends, temperature variation, and overall energy breakdown.

CONCLUSION

This mini project successfully demonstrates an efficient building automation system for managing lighting and HVAC using feedback control. The combination of occupancy-based control and PID temperature regulation greatly enhances energy efficiency. The simulation results show significant reductions in energy consumption and operational costs. This model can be expanded into real-world smart buildings, IoT-based automation, and industrial energy management applications.