Energy Efficiency Assessment in Smart Homes: A Comparative Study of Energy Efficiency Tests

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Abstract: This study covers a broad range of energy efficiency techniques by highlighting cost savings, user behavior analysis, and smart grid integration. Energy efficiency tests were conducted to compare the performance of various smart home technologies, including solar panels, lighting controls, and energy monitoring systems. The research promotes holistic efficiency, future study fields include long-term evaluations, user behavior analysis, and smart grid integration.

Keywords: Energy efficiency, smart homes, smart appliances, comparative study, sustainability

1 INTRODUCTION

The shift to energy-efficient settings is an essential part of this shift. Reduced energy consumption is promised by the integration of energy-efficient devices in smart homes. Among these efficient devices that are often seen in smart homes. Among these efficient devices, this research article emphasizes the need for studies that assess the energy efficiency of smart home technology, such as solar panels, lighting controls, and energy monitoring systems. The energy efficiency of smart home technology, such as solar panels, lighting controls, and energy monitoring systems, was thoroughly assessed by the study. Notable energy savings were achieved by energy-efficient settings; smart ovens, washing machines, and refrigerators had average efficiency ratings increased dramatically. During times when the thermostat is not active, smart thermostats preserve comfort while cutting energy consumption by an average of 1°C. Our study not only looks at these technologies but also assesses factors like solar panel performance, energy efficiency, and the integration of renewable energy sources. As a result, scientists, engineers, and legislators are now putting a lot of emphasis on energy efficient technology in smart homes. Innovations in energy efficiency, future study fields include long-term evaluations, user behavior analysis, and smart grid integration.

1 Scope of the Study

Our study not only looks at these technologies but also assesses factors like solar panel performance, energy efficiency, and the integration of renewable energy sources. As a result, scientists, engineers, and legislators are now putting a lot of emphasis on energy efficient technology in smart homes. Innovations in energy efficiency, future study fields include long-term evaluations, user behavior analysis, and smart grid integration.
2 REVIEW OF LITERATURE

1 Technology for Smart Homes and Energy Efficiency

The consumption was expressed in kilowatt hours (kWh) for each appliance. Predetermined intervals (e.g., every 15 minutes) were used to record the data. A collection of representative smart gadgets was deployed in a smart home setting to evaluate their impact on energy usage. The study's research approach was extensive data collecting procedure intended to evaluate the energy efficiency of smart home devices. For the course of the research, data loggers were set up to record data at predetermined intervals. These gadgets included energy monitoring systems, smart thermostats, washing machines, cookers, and refrigerators. In order to replicate real-world use, the gadgets were deployed in a controlled domestic environment.

The idea of “smart homes,” which are defined by the incorporation of automation systems and cutting-edge technology, has been more popular in recent years. The term “smart home technologies” refers to a broad category of equipment and systems that can be sold back to the grid. Installing households with solar panels may significantly lower energy costs and, in some situations, even provide extra power that can be sold back to the grid. According to research, one important tactic for lowering dependency on conventional grid power sources is the incorporation of solar panels.

In residential settings, efficient temperature regulation is essential to energy efficiency. The capacity of smart thermostats may result in significant energy savings. Research has shown that energy consumption of smart appliances, such as washing machines, ovens, and refrigerators, may be considerably decreased by using features like remote control, smart thermostats, and cutting-edge technology.

Enhancing energy efficiency in smart homes has also been made possible in large part by smart lighting systems. It has been shown that the flexibility of remotely altering lighting, modifying brightness levels, and creating automated lighting schedules leads to large energy savings. Smart devices are equipped with the ability to optimize energy usage. Research has shown that energy consumption of smart appliances, such as washing machines, ovens, and refrigerators, may be considerably decreased by using features like remote control, smart thermostats, and cutting-edge technology.

3 Research Questions and Gaps

There is little data on how several energy-intensive items and habits affect energy consumption in households. This methodology will provide a comprehensive viewpoint on the combined influence of various technologies. A number of studies have indicated that energy monitoring systems, smart thermostats, and smart lighting systems may result in significant energy savings. However, there are few studies that actually compare how well various smart home technologies work in actual situations.

There are few studies that actually compare how well various smart home technologies work in actual situations. This methodology will provide a comprehensive viewpoint on the combined influence of various technologies. A comprehensive, comparative studies are still needed, even though the literature now offers insightful information on the relative effectiveness of different smart home systems in improving energy efficiency. Among the gaps identified, there is a need for more comprehensive studies on the impact of smart home technologies on household energy use, hence advancing our comprehension of their practical efficacy.

6 Research Questions and Gaps

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3 RESEARCH METHODOLOGY

1 Data Gathering

Data recording: To record user interactions, operating metrics, and energy usage, every smart device was outfitted with data recording capabilities. For the course of the research, data loggers were set up to record data at predetermined intervals. These devices included energy monitoring systems, smart thermostats, washing machines, cookers, and refrigerators. In order to replicate real-world use, the gadgets were deployed in a controlled domestic environment.

Measurement of Energy Consumption: For all relevant equipment, energy consumption was expressed in kilowatt hours (kWh). For ease of comparison, data for standard and energy-efficient devices work together in a single smart home setting.

2 Installation and Monitoring of Smart Devices

Installation and Monitoring of Smart Devices: The study's research approach included an extensive data collecting procedure intended to evaluate the energy efficiency of different smart home devices. These developments might lead to increased sustainability overall and lower energy costs.
3 Monitoring of Solar Panel Performance

- Measurement of Solar Panel Output: To determine the output in kilowatts (kW), data loggers were installed on the solar panels. Regular data collection was done to track changes in energy production.
- Meteorological Information: To correlate solar panel performance, nearby meteorological stations provided information on solar irradiance, ambient temperature, and sunshine hours.

4 Analyzing Data

An essential part of this study, which sought to measure the energy efficiency of smart home technology, was data analysis. The following methods were used to examine the information:

5 Metrics for Energy Efficiency

- Energy Consumption Reduction: The amount of energy saved by using smart appliances' energy-efficient settings was measured.
- Energy Star Ratings: To assess the energy efficiency of smart appliances and lighting systems, Energy Star ratings were taken into account where appropriate.
- Efficiency of Temperature Control: The efficiency of temperature control was evaluated by the examination of temperature fluctuations and their associations with external factors.
- Solar Panel Efficiency: The actual energy production of the panels was compared to the output predicted by the weather, in order to determine its efficiency.

6 Comparative Study

To assess the relative energy efficiency of each technology, data from numerous smart devices was gathered and analyzed, including before and after data for different settings. The identification of possible synergies when many technologies were used simultaneously was another goal of the data analysis.

7 Test-Based Design

A randomized experimental approach was used in the research to reduce bias and account for confounding factors. Various situations and use patterns were simulated in a controlled manner inside the smart home environment.

4 RESULT AND ANALYSIS

1 Consumption of Smart Appliance Energy

- Smart Refrigerators: Compared to regular settings, smart refrigerators showed an average 10% decrease in energy usage while operating in energy-efficient mode. This decrease was made possible in large part by the use of sophisticated compressor algorithms and better insulation.
- Smart Washing Machines: When in energy-efficient mode, smart washing machines with load optimization functions demonstrated a 15% decrease in energy use. Energy was saved by these gadgets' clever adjustments to wash cycles and water levels.
- Smart Ovens: When operating in energy-efficient mode, smart ovens with enhanced insulation and optimized preheat time resulted in an average 12% decrease in energy usage. These ovens used less energy while still producing delicious food.

<table>
<thead>
<tr>
<th>Smart Device</th>
<th>Energy Consumption (Before)</th>
<th>Energy Consumption (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Bulb</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Smart Thermostat</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Smart Refrigerator</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Smart Washing Machine</td>
<td>100</td>
<td>85</td>
</tr>
<tr>
<td>Smart Oven</td>
<td>150</td>
<td>130</td>
</tr>
</tbody>
</table>

TABLE I. Energy Consumption Comparison (kWh)
When appropriate, Energy Star ratings were used to evaluate the energy efficiency of lighting and smart appliance systems. The following were the findings of this evaluation:

- **Smart Dishwashers:** When used in energy-efficient mode, smart dishwashers’ Energy Star rating went from 2 to 3. This change demonstrated how much more energy and water-efficient these gadgets were without sacrificing cleaning effectiveness.

- **Smart Lighting Systems:** A significant increase in energy efficiency has been shown by smart lighting systems, which include smart lighting controllers and smart bulbs. When energy-efficient lighting schedules were implemented, smart lighting systems’ Energy Star ratings went from 3 to 4, highlighting the potential for energy savings.

### TABLE II. Energy Efficiency Ratings

<table>
<thead>
<tr>
<th>Smart Appliance</th>
<th>Energy Star Rating (Before)</th>
<th>Energy Star Rating (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Washer</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Smart Dishwasher</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Smart Oven</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Smart Dryer</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Smart Refrigerator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart Bulb</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Energy Consumption Comparison (kWh)](image_url)

![Energy Efficiency Ratings](image_url)
3 Temperature Regulation Effectiveness

Through analysis of temperature fluctuations and relationships with external variables, the efficacy of temperature control systems was evaluated. The following conclusions were noted:

- **Smart Thermostats**: By efficiently regulating interior temperature, smart thermostats preserve intended comfort levels. These thermostats achieved an average temperature drop of 1°C during unoccupied times when paired with meteorological data and occupancy patterns, saving energy without compromising comfort.

<table>
<thead>
<tr>
<th>Smart Thermostat</th>
<th>Average Temperature (Before)</th>
<th>Average Temperature (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Room</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Bedroom</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Kitchen</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Bathroom</td>
<td>23</td>
<td>22</td>
</tr>
</tbody>
</table>

**Fig. 3.** Temperature Control Efficiency (in °C)

4 Performance of Solar Panels

The actual energy production of the solar panels was compared to the output predicted by the weather, in order to assess their effectiveness. The following was disclosed by the results:

- **Solar Panels**: The average energy production of the solar panels was almost in line with the output predicted by the weather and sun irradiance, indicating a consistent performance. According to the statistics, the solar panels produced a dependable supply of power, which helped to lessen reliance on the grid.

<table>
<thead>
<tr>
<th>Date</th>
<th>Solar Panel Output (Before)</th>
<th>Solar Panel Output (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-01-2023</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>01-04-2023</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>01-07-2023</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>01-10-2023</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>01-13-2023</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>01-16-2023</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>01-19-2023</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>01-22-2023</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>01-25-2023</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**TABLE III.** Temperature Control Efficiency (in °C)

**TABLE IV.** Solar Panel Performance (in kW)
5 A Comparative Study

A comparative study of data gathered from several smart devices showed the potential benefits of combining many energy-saving technologies in a smart home. For example, when smart thermostats and lighting controls were combined, energy savings increased because the HVAC and lighting systems optimized energy use.

6 Conversation and Consequences

The results of this research highlight how using energy-efficient technology in smart homes may result in considerable energy savings. The energy usage of smart appliances, including washing machines and refrigerators, has been shown to be much lower, which helps save money and protect the environment. The potential of smart appliances and lighting systems to achieve energy efficiency regulations is further shown by their enhanced Energy Star ratings. The ability of smart thermostats to keep houses at acceptable temperatures while using less energy emphasizes the need for sophisticated HVAC control systems in energy-conscious buildings. Moreover, solar panels' dependable performance highlights how renewable energy sources may be used to lessen reliance on the grid. The comparative study shows that combining many energy-efficient technologies may lead to synergistic effects. Homes may maximize energy consumption and improve energy efficiency by coordinating the functioning of smart gadgets.

5 CONCLUSION

The domestic energy landscape has seen a radical transformation due to the rapid advancement of smart home technologies, which are fueled by a rising consciousness of environmental sustainability and energy conservation. Solar panels, lighting controls, thermostats, and smart appliances have become revolutionary instruments that promise to save energy and lessen their negative effects on the environment in addition to improving convenience. In order to evaluate these technologies' energy efficiency in the real world and provide insightful information for the larger conversation about sustainable living, a comparison study was conducted and reported in this research paper.

1 Main Results

- Energy Consumption of Smart Appliances: When used in energy-efficient settings, smart ovens, washing machines, and freezers showed significant savings in energy use. These reductions, which average between 10% and 15%, demonstrate the possibility of significant energy savings without sacrificing performance.
- Energy Star ratings: When switched to energy-efficient modes, smart dishwashers and lighting systems saw a considerable improvement in their scores, demonstrating their ability to satisfy strict energy efficiency criteria.
- Temperature Control Efficiency: With an average temperature drop of 1°C, smart thermostats efficiently maintained interior temperature settings while using less energy while the house was empty.
- Solar Panel Performance: By providing a dependable renewable energy source and lowering reliance on the grid, solar panels regularly produced power that roughly matched predicted outputs depending on weather conditions.
- Comparative Analysis: By combining several energy-saving devices in a smart home setting, synergistic opportunities were identified that would enable homeowners to maximize energy savings and improve energy efficiency.

2 Repercussions

- Cost Savings: By lowering power costs and prolonging the lifespan of these products, energy-efficient smart lighting systems and appliances may save homeowners a lot of money.
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