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Article

Analysis and methodological design for the implementation of a home electrical energy loss detection system

Análisis y diseño metodológico para la implementación de un sistema de detección de pérdidas de energía eléctrica en el hogar

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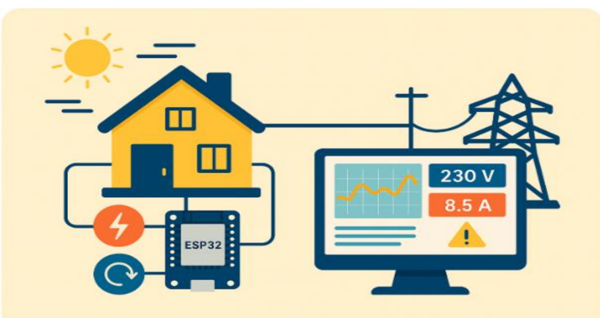
Abstract

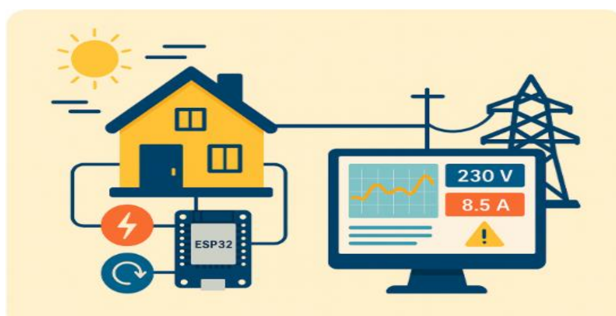
The project "Home Energy Loss Monitoring and Detection System [SMDPED]" aims to document the technical and structural planning required for its future implementation. This work outlines the organized structure of activities necessary to initiate the development of the energy monitoring project. Five key components were defined: needs analysis, conceptual design, component selection, functional integration, and preliminary validation. Each was designed to ensure consistency between the stated objectives and the technological decisions made, prioritizing accessibility, low cost, and practical application in residential settings. The selection of tools such as the ESP32 microcontroller, electrical sensors, SQL Server databases, and a platform built in ASP.NET Core MVC was based on compatibility, scalability, and simplicity. This article demonstrates that a well-structured planning process is essential to transform a technical need into a functional, replicable solution aligned with the current challenges of energy efficiency in the home.



Home energy monitoring, Energy efficiency, ESP32 microcontroller, SQL Server, ASP.NET Core MVC, System planning

Resumen

El proyecto "Sistema de Monitoreo y Detección de Pérdidas Energéticas Domésticas [SMDPED]" tiene como objetivo principal documentar la planificación técnica y estructural necesaria para lograr su implementación. Este trabajo describe la estructura organizada de actividades necesarias para dar inicio al desarrollo del proyecto de monitoreo energético. Se definieron cinco etapas: análisis de necesidades, diseño conceptual, selección de componentes, integración funcional y validación preliminar. Cada una fue diseñada para asegurar coherencia entre los objetivos planteados y las decisiones tecnológicas adoptadas, priorizando accesibilidad, bajo costo y aplicación práctica en entornos residenciales. La elección de herramientas como el microcontrolador ESP32, sensores eléctricos, bases de datos SQL Server y una plataforma en ASP.NET Core MVC responde a criterios de compatibilidad, escalabilidad y simplicidad. Este artículo demuestra que una planeación bien estructurada es clave para convertir una necesidad técnica en una solución funcional, replicable y alineada con los retos actuales de eficiencia energética en el hogar.



Monitoreo energético doméstico, Eficiencia energética, Microcontrolador ESP32, SQL Server, ASP.NET Core MVC, Planificación de sistemas.

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Introduction

The constant increase in residential electricity consumption and the lack of awareness about efficient energy use have created a need to develop accessible solutions that enable families to identify and correct energy losses in their homes. Often, energy waste is not obvious to users, whether due to installation faults, equipment in poor condition, or inefficient habits. In this context, the project called the Domestic Energy Loss Monitoring and Detection System [SMDPED] has emerged as a proposal to lay the foundations for a technological solution that facilitates the identification of these situations.

In recent years, households have become one of the main sources of energy consumption worldwide. According to data from the International Energy Agency [IEA], the residential sector accounts for about 30% of total final energy consumption, with electricity being one of the main resources used for lighting, air conditioning, appliances, and electronic systems. This trend has increased due to population growth, the rise in the number of connected devices, and changes in consumption habits, especially following the rise of working and studying from home.

Historically, the management of electricity consumption in the home has been passive, limited to the periodic payment of bills and, at best, the use of low-consumption appliances. However, advances in technology, especially the development of microcontrollers, smart sensors and web interfaces, have opened up the possibility of creating active solutions that measure consumption in real time, detect anomalies and present understandable information to the end user. This digital transformation in the home has given rise to new approaches that not only save money but also raise awareness about the rational use of energy. The transition to more efficient technologies is not only a technical necessity but also an environmental goal. Energy waste has a direct impact on the increase in greenhouse gas emissions, especially in countries where the energy matrix depends on fossil fuels. From this perspective, every initiative that contributes to improving energy use in the home becomes a significant action within the framework of the Sustainable Development Goals [SDGs], particularly SDG 7 [affordable and clean energy] and SDG 13 [climate action].

This article does not address the physical construction of the system or experimental testing, but focuses exclusively on the technical planning, methodological structuring and selection of technological tools necessary for its future implementation. Documenting this initial phase ensures that decisions are based on criteria of feasibility, functionality and accessibility, establishing a solid framework that minimises risks in the following stages.

To this end, five key stages were defined: needs analysis, conceptual design, component selection, functional integration, and preliminary validation. These phases allow the work to be organised, facilitate decision-making, and ensure that the project is aligned with its central purpose: to build a functional, replicable, and useful tool to promote energy savings in domestic environments.

The choice of technologies such as the ESP32 microcontroller, voltage and current sensors, SQL Server databases and an ASP.NET Core MVC visualisation platform responds to a strategy that prioritises low cost, compatibility and ease of use. These decisions are aimed at facilitating its future implementation in real homes, without requiring advanced technical knowledge or large investments, enabling its application as an educational tool, for family monitoring or institutional support.

In summary, this article presents a methodological approach that seeks to lay the foundations for the development of a technological solution focused on domestic energy monitoring. Through clear and structured planning, it demonstrates that it is possible to transform a technical need into a viable, scalable project with a positive impact on both the economy and the environment.

Methodology

From its initial conception, the SMDPED project was aimed at building a solid foundation to guide its future development. Instead of focusing on the immediate construction of the system, a reflective phase was chosen, centred on understanding the problem, structuring its components and establishing a clear and well-founded work plan.

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This stage was conceived as a strategic planning exercise, in which the priority was to define the process precisely, rather than to obtain a functional prototype or carry out experimental tests. Thus, the project advanced as a methodological proposal that seeks to shape a technical solution based on analysis and systematic organisation of development.

It all began with an analysis of the problem, which made it possible to precisely define the scope of the project. The lack of accessible domestic tools for monitoring electricity consumption and detecting energy losses was identified. Based on this diagnosis, the objectives were defined, the criteria for success were established, and technical feasibility was prioritised over complexity, ensuring that the project could be developed within the available resources.

With the objectives clearly defined, a work plan was drawn up, divided into blocks of activities. Estimated times were assigned, dependencies between tasks were identified, and a progressive execution line was constructed. This organisation facilitated the visualisation of the workflow, allowed informed decisions to be made at each stage, and served as a guide to maintain the direction of the project.

Subsequently, a technical review was carried out to choose the most suitable components and tools. The ESP32 microcontroller was chosen for its versatility, along with accessible electrical sensors [ACS712 and ZMPT101B], an SQL Server database for data storage, and an ASP.NET Core MVC web platform for data visualisation. This selection was based on both functional criteria and ease of integration.

The first conceptual diagrams of the system were then drawn up, defining the flow of information from measurement to visual representation. This initial design made it possible to anticipate potential limitations, establish validation points, and predict the expected behaviour of the system before any practical implementation.

During the development of the documentation, each step forward was recorded in technical logs, where decisions, adjustments, setbacks and solutions applied were noted.

This practice made it possible to maintain control of the process, evaluate the completion of activities and facilitate a retrospective analysis useful for future implementations.

Box 1

Figure 1
Conceptualisation of the Project Development Process

All technological decisions were evaluated and validated theoretically, but without making physical connections or testing on actual devices.

The proposed integration—between hardware, software, and database—was approached as a structural simulation that would serve as a framework for a future phase of physical development.

Finally, all the information generated was consolidated into a comprehensive technical report, including plans, diagrams, code snippets, database structures, and functional diagrams of the platform. This compendium not only demonstrates the validity of the methodological process, but also serves as a guide for its replication, improvement, or future expansion.

Through this structured process, the project demonstrated that clear and well-documented planning is essential for turning a technical idea into a functional, replicable solution aligned with real energy efficiency objectives.

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The methodological approach allowed us to build a solid foundation that supports not only the final product, but also the entire journey to get there.

Results

Evaluation of the Planning Process

1. Control of the Development Process

The project development was expected to follow a predefined schedule for each work block [analysis, planning, component selection, assembly and integration, functional testing].

This monitoring would allow for an evaluation of whether the technical planning was realistic and whether the team could meet the established deadlines.

In general, the first activities [analysis and planning] were completed as scheduled. However, activities related to component selection and system assembly experienced slight delays due to adjustments in the choice of sensors and errors during initial integration.

Testing also took longer than originally estimated, mainly due to code adjustments and data collection under real conditions.

Box 2

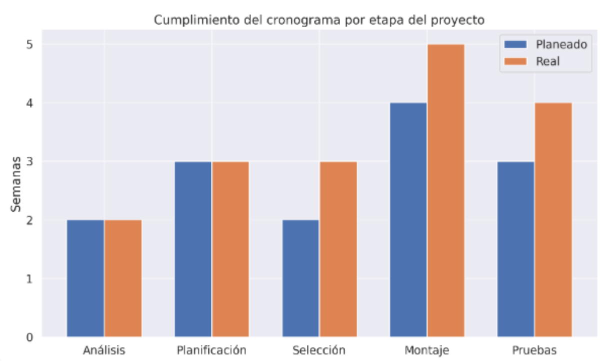

Figure 2

1. Distribution of Technical Effort during the Process

During the development of the project, a balanced distribution of time between the different activities was anticipated, especially between the technical part [assembly and programming] and the analytical part [research, documentation and testing]. The idea was not to overload any one area of work in order to ensure a sustainable and well-documented progress.

The time analysis shows that the most demanding tasks were electronic assembly and programming, each accounting for about a quarter of the total time. Technical research and testing occupied similar slots, while documentation - although necessary - was executed with less time burden due to its progressive integration during the project.

Box 3

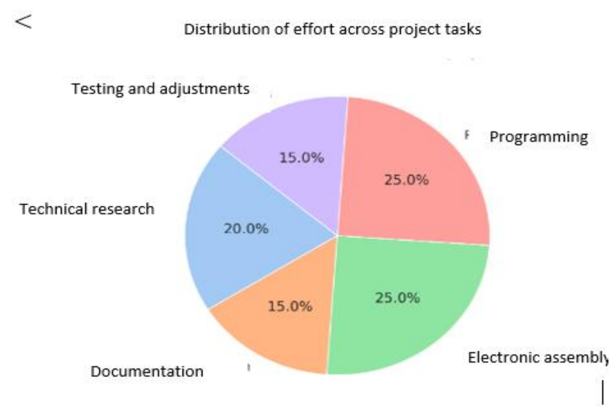

Figure 3

2. Weekly Progress Monitoring

A key part of the project process was to keep a continuous record of progress on a weekly basis. This not only facilitated short-term decision making, but also allowed for assessment of the pace of work, identification of possible delays and reinforced accountability.

Weekly monitoring showed a steady progression in the execution of tasks, with slight variations depending on the complexity of the activities in progress. There were weeks with lower productivity - associated with research or integration - and others with a higher concentration of deliverables, such as in the testing and documentation stages.

Box 4

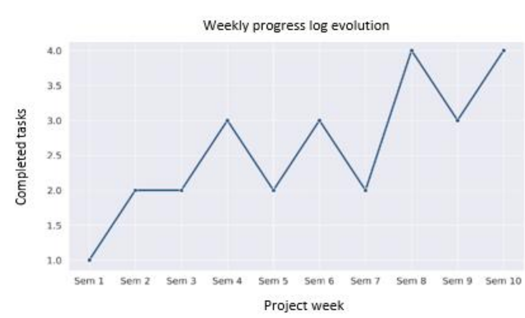

Figure 4

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3. Current status of the project according to its structural process.

The main objective of this work was to lay the methodological and technical foundations for the future construction of the SMDPED project. Through documentation, architecture design, component selection and schematic elaboration, the necessary foundations were laid to start the implementation of the project.

This result clearly shows how far advanced the project preparation is.

To have a solid, complete and validated process structure in place so that, in later phases, the team can start development without the need to redesign or redefine the technical objectives.

Box 5

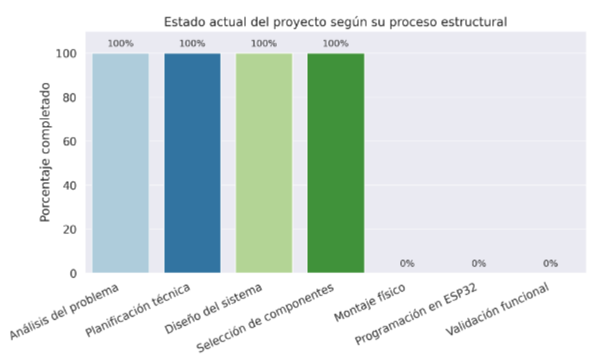

Figure 5

Conclusions

El proyecto "Sistema de Monitoreo y Detección Domestic Energy Losses" has achieved its main objective at this stage: to establish a technical and methodological process that will serve as the basis for its subsequent implementation. Through a structured analysis of the problem, the definition of clear objectives, and the careful selection of technological components, a development roadmap was designed that will allow future construction to begin with a solid frame of reference.

No physical prototype was developed, nor were any functional field tests carried out, as this stage focused exclusively on planning, organising activities, selecting tools and technical documentation. This approach made it possible to anticipate requirements, foresee possible limitations and reduce uncertainty ahead of the next phase.

One of the main achievements was the consistency between what was planned and what was structured. The technical decisions made at this stage remain valid and appropriate, which is a significant advantage in ensuring that, once physical development begins, unnecessary rework and detours are avoided.

In summary, the project is at a transition point: it has successfully completed its preparation phase and has the necessary elements—both technical and methodological—to move forward with its construction. The clarity of the designed process is one of the most important assets of this stage and will serve as a guide for those carrying out the next phase of implementation.

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