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Environmental impacts related to the commissioning and usage phase of an intelligent energy management system

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HIGHLIGHTS

- An intelligent energy management system for underground metro stations is examined.
- The assembly phase involves an environmental impact of 897.02 Eco-indicator'99 points.
- The monitoring subsystem dominates the environmental impact.
- Considering a 5–10-year lifespan, the impact ranges between 1963 and 3029 Eco-points.
- The impact on resources is the largest, followed by human health and ecosystem quality.

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ABSTRACT

This paper presents for the first time the results of a life cycle assessment study for an intelligent energy management system. We considered material acquisition, manufacturing, transportation, assembly, operation and maintenance stages. The results show that the assembly phase had an environmental impact of 897 Eco-indicator 99 points that was mainly due to the monitoring subsystem (87.80%). When the analysis was extended to cover the use phase, the environmental impact ranged from 1963 (useful life of 5 years) to 3029 Eco-indicator 99 points (useful life of 10 years). The environmental impact of the use stage was found to represent 54–70% of the total, whereas the assembly stage represented 46–30%. The maintenance phase contributed to a very small extent to the total environmental impact (less than 0.5%). In any case, the impact on resources was the largest (about 51%), whereas the human health damage category amounted to approximately 35% and the ecosystem quality damage category represented about 14% of the total impact.

1. Introduction

Many approaches have been found related to life cycle assessment (LCA) within the scope of the broadly defined building industry. According to Ortiz et al. [1], Pajchrowski et al. [2] and Cabeza et al. [3], and within the framework of the top-down approach, the whole building and its entire life cycle are objects of consideration. In the bottom-up approach, the focus is limited to individual materials, components, subsystems or systems. However, to the authors' knowledge, none of the existing initiatives on life cycle analysis address individual systems for managing buildings' energy consumption. Only van Dam et al. [4] explored the effectiveness of home energy management systems taking into account not only the energy savings provided by the system but also the energy needed for its production, use and disposal. Energy management systems have been proved to provide considerable benefits in terms of net energy savings [4] but the full range of environmental impacts related to the whole life cycle of intelligent management systems has not been investigated till now. Although application of information and communication technology (ICT) is often expected to result in decreased environmental impacts [5], several studies focusing on consumer products such computers [6–8 and 9], monitors [10–13 and 14], mobile phones [15] and TVs [16] have addressed their negative impacts [17]. Therefore and taking into account the results reported by previous research initiatives within the field of ICT products, it is important to assess the broad spectrum of environmental impacts of devices and components composing intelligent energy management systems during all lifecycle stages. In this sense, life cycle assessment is a widely

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recognized instrument for assessing the environmental aspects and potential impacts associated with all the stages of a product's life by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts, and interpreting the results [18].

Thus, the main objective of this paper is to contribute to a better understanding of the whole range of environmental impacts related to the commissioning and usage of an intelligent energy management system. The following section describes the energy management system under study. Section 4 presents the methodology used to evaluate its life cycle impacts, which was focused on the material acquisition, manufacturing, transportation, assembly, operation and maintenance stages. This is followed by a discussion of the results and concluding remarks.

2. Description of the energy management system

The analysis focuses on an advanced energy management system developed under the auspices of the European research project entitled Sustainable Energy mAnageMent for Underground Stations (SEAM4US) [19]. The SEAM4US energy management system provides smart autonomous control of ventilation, lighting and vertical transportation through the core, monitoring and control subsystems (Fig. 1). It has been implemented in a representative underground station of the Barcelona metro network (pilot station) [20].

2.1. Core subsystem

The core subsystem remotely manages and supports the monitoring and control subsystems. Due to the strict security policies of public transport operators, the core subsystem cannot be cloud-based and must be located in the operator's control centre. Therefore, a communication infrastructure is needed to integrate the SEAM4US energy management system within the existing operational procedures. The core subsystem is comprised of a centralized server and a backup hard drive disk, holding the central instance of the SEAM4US software.

2.2. Monitoring subsystems

The monitoring subsystem creates almost real-time awareness of the station's manageable subsystems. Ventilation control strategies require the monitoring of environmental data, such as surface temperature, relative humidity, air pressure, air speed, pollutants (CO_2 and PM10), outdoor conditions (solar radiation and rain accumulation) and energy consumption, whereas lighting and escalator control requires real-time data on crowd density and energy consumption.

2.2.1. Environmental monitoring subsystem

The wireless environmental monitoring network captures ambient data for modelling validation and control feedback. It includes an extensive set of supported sensors (more than 100 units were used in the pilot), communication hardware, as well as management and data handling software. Environmental monitoring is carried out through a dense multihop sensor network, in which network management is optimized and battery replacements are reduced. Wireless deployment also avoids hundreds of meters of cables. In order to monitor outdoor conditions and to predict future behaviour, a weather station is placed outside the station and a weather forecast service is used.

2.2.2. Energy monitoring subsystem

The energy consumption monitoring subsystem is aimed at generating energy consumption baselines for the pilot station. It uses detailed energy consumption data from individual subsystems and gives real-time feedback on the energy management system performance. For fairly stable loads such as lighting systems or ventilation, a single smart meter measures multiple power lines. This solution enables the wireless transfer of measurement data (via ZigBee networks), but with reduced monitoring frequency. For highly variable loads such as escalators and elevators, a high performance solution measures few power lines at once, but with high frequency. In this case, measurement data is transferred through RS485 and Modbus/TCP protocols.

2.2.3. Occupancy detection subsystem

The occupancy detection subsystem provides an estimation of the crowd density of the spaces in the station with less than 20% error. Unlike all other SEAM4US subsystems, the occupancy monitoring subsystem relies on closed-circuit television (CCTV) infrastructure that is already installed in the station. The use of 20 existing cameras greatly reduces the costs and deployment time, although greater effort is required to create reliable computer vision algorithms. The video processing algorithm and the SEAM4US software interfaces that enable communication with the backend systems are implemented in the CCTV device proxy software. This software runs in the CCTV gateway (desktop computer running Windows 7) at the pilot station and receives the video stream from a dedicated recorder. Algorithm results are sent to the SEAM4US server.

2.3. Control subsystem

The control subsystem is responsible for acting on the existing ventilation, lighting and vertical transportation subsystems to reduce the underground station's energy consumption. At the same time, and according to the premises stated by the metro operator, passenger comfort must not be compromised, minimally invasive interventions must be prioritized and the current operator's controllers' tasks must not be modified by SEAM4US actions. This means that the energy management system must be transparent and seamlessly integrated with current operator policies.

The ventilation control system is based on a model predictive control (MPC) approach that considers current building status, the short-term weather forecast, train transit, an occupancy prediction and the estimation of future building status [21]. In order to determine in advance the optimal control policies and anticipate the reaction to external forces [22], the controller includes an optimization algorithm that, at each step, generates a set of candidate control actions, predicts the future status of the building through the embedded model, and selects the optimal action through a scenario analysis. The predictive model is adaptive, as it has learning capabilities and is continuously updated with a feed of actual monitored data life-long. The commands are transferred to the ventilation system through new programmable logic controllers (PLC). PLCs modulate the fans' speed by controlling the corresponding variable frequency drives.

The lighting subsystem is regulated taking into account the two main criteria stated by the metro operator: (1) not to diminish the passenger's feeling of security and (2) to fulfil the minimum lighting levels required by current regulations. In light of the above, it was assumed that a good lighting level is required when there are only a few people in the station, whereas when the occupancy is higher, the minimum lighting level will be enough to perform the visual task. Thus, the lighting control system benefits from real-time crowd density data gathered by the occupancy monitoring subsystem and the user model. These data provide an