Renewable and Sustainable Energy Reviews 55 (2016) 662–667

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy performance assessment of an intelligent energy management system

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ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
20 July 2015
Accepted 12 November 2015

Keywords:
Energy management system
Energy consumption
Cumulative energy demand
Life cycle assessment
Life cycle energy analysis
Underground station
Metro network

ABSTRACT

Although energy management systems are expected to result in decreased energy consumption, it is important not to overlook the energy used until commissioning (including raw materials acquisition, manufacturing and transportation) and during the usage phase (including operation and maintenance). This paper examines the energy performance of an intelligent energy management system for underground metro stations. The results show that the energy management system has high energy performance in terms of energy payback time and energy return factor, due to its low cumulative energy demand and its potential for energy savings. When we assumed that the lifespan of energy management systems may vary between 5 and 10 years, their cumulative energy demand was found to range between 505,316 and 852,493 MJ_p eq. In all cases, the operating energy was found to far outweigh the embodied energy (68–81%). The energy management system was implemented in a pilot underground station and was found to provide an energy saving of 13.2 ± 1.1% of the total energy consumption of the pilot station. The energy payback time of the energy management system for underground stations was found to range between 40 and 55 days. Consequently, the system pays back between 33 and 91 times the energy invested in it. The results of this research provide valuable information for stakeholders in the energy management systems industry, as they contribute to ascertaining the sustainability of products.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.11.006
1364-0321/

1. Introduction

Since buildings are responsible for about 40% of the total primary energy consumption [1], significant research efforts have been recently directed towards energy optimisation [2] through the implementation of automated control systems and intelligent optimisation strategies [3]. Energy management systems have gained popularity as they contribute to continuous energy management of active building systems such as heating, ventilation and air-conditioning [4,5], but their environmental implications have not been researched in depth. While they can be considered almost absolutely eco-friendly during their operational phase, it is important to evaluate the energy consumed until commissioning and usage by the devices in the system, to ascertain their sustainability. In a thorough literature review, we found no relevant studies related to this research area. Only van Dam et al. [6] assessed the life cycle impact of energy management systems. They focused on three domestic energy management systems and concluded that results are highly dependent on the complexity of the system. Gangolells et al. [7] conducted a Life Cycle Analysis of an advanced energy management system developed under the auspices of a European research project entitled "Sustainable Energy Management for Underground Stations" (SEAM4US) [8]. Unlike home energy management system, the SEAM4US energy management system is implemented in a public space and involves multiple systems and equipment, multi-storey underground spaces, and massive flows of people [9]. Even more complexity is added to the system by the fact that it manages a very large environment with multi-faceted thermal behaviour (i.e. intricate air exchange dynamics with the outside, heat conduction with the surrounding soil and high variable internal gains due to travelling passengers and trains) [10], and there are operational restrictions derived from the need to guarantee the reliability of the transport service and the security, safety and comfort of the customers. Results obtained in Gangolells et al. [7] showed that the environmental impact of the SEAM4US system ranged from 1963 (useful life of 5 years) to 3029 Eco-indicator 99 points (useful life of 10 years). 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.

The present research focuses on the analysis of the energy performance of the SEAM4US energy management system and its main objective was to evaluate whether direct energy saving achieved by the energy management system is greater than the energy consumed by the system during its manufacturing, assembly, use and maintenance phase. First, we quantified the primary energy requirements of the energy management system by examining the commissioning and usage phases (including raw materials acquisition, manufacturing, transportation, operation and maintenance) and assessing the corresponding contributions. Then, we calculated the time required for the SEAM4US energy management system to save the amount of energy consumed during its initial life cycle stages and how many times the system pays back this energy, taking into account the energy saving provided by the SEAM4US energy management system. Following this introduction, we describe the SEAM4US energy management system and its main functionalities. In Section 3 we describe the methodology. Finally, the results are discussed in Section 4 and conclusions and future work are detailed in Section 5.

2. The SEAM4US energy management system

Underground metro stations are major consumers of electricity. However, research on reducing their energy consumption has mostly been focused on improving the energy efficiency of the trains. The infrastructure has been a secondary target, even though electricity consumption in stations can amount to up to 30% of total energy expenditure [9]. Given the huge size of metro networks and the current economic context, it is not feasible to upgrade all equipment for the sole purpose of improving energy efficiency. Thus, improvements in energy management must be sought, although we should take into account that current energy management policies adopted by metro operators consist mainly in on/off schedules that reflect inherited habits more than analysed needs. Along this line, the primary aim of the European research project entitled "Sustainable Energy Management for Underground Stations" [8] is to reduce energy consumption in underground metro stations by developing an intelligent real-time energy management system that can produce significant energy savings in non-traction electricity consumption. Control policies were defined in accordance with the results obtained during the energy audit of the prototype underground station [9]. Taking into account that the metro station was found to be over-illuminated to enhance passenger safety, the lighting subsystem is regulated through logical feed-forward control that varies the illuminance level based on the expected occupancy of the spaces and the visual task of the passengers. A good lighting level is considered necessary in the case of low occupancy, as a lack of lighting in this situation could make passengers feel unsafe. In contrast, the minimum lighting levels required by regulations are considered sufficient to perform the visual task when occupancy is high. Platform ventilation is currently provided by two reversible fans following day–night and seasonal cycles. Fans run at top speed to keep temperature levels as low as possible during the summer. In winter, the speed is reduced, since the main purpose is to control air quality, rather than to provide thermal comfort. In all cases, station fans are switched off during the night. The SEAM4US system regulates the ventilation subsystem by means of an environmental prediction model that considers the actual building's environmental conditions, the prediction of near future disturbance processes (including weather conditions, train arrivals and expected passenger flows) and prediction of the future building status [11]. Finally, the control policy within the vertical transportation subsystem is based on setting the escalators' speeds at lower values than the nominal one when conditions of low traffic are predicted by the occupancy detection subsystem.

These control policies were implemented trough the core, monitoring and control subsystems. The core system provides central processing and storage capacity remotely to the SEAM4US energy management system. It includes a centralized server for hosting the software and databases, and for facilitating access to other SEAM4US devices at stations. The core system also includes shared storage used for periodically storing backups of SEAM4US data. The environmental monitoring network captures the ambient data in the station to model validation and control feedback. The subsystem includes an extensive set of sensor nodes, communication hardware and management and data handling software. Sensor nodes include multiple environmental sensors for measuring air and surface temperature, air flow, air pressure, CO_2, PM10, relative humidity, as well as basic outdoor measurements such as solar radiation and rain accumulation. Some sensor nodes are battery operated, whereas others have batteries only as a backup power source for situations in which wired power supply is temporarily lost. Sensor nodes measure data and transmit it to the gateway node, which in turn forwards data to the WSN gateway (computer hosting local database server software, and providing interfaces to the sensor network's management user interface). The occupancy detection subsystem is used to assess and predict station occupancy. This subsystem relies on 20 existing closed-circuit television (CCTV) cameras distributed throughout the station. The multiple