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Experimental assessment of the energy consumption of urban rail vehicles during stabling hours: Influence of ambient temperature

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HIGHLIGHTS

- Energy use of stabled vehicles in an actual metro system is experimentally examined.
- Stabling hours account for about 11% of the vehicles' total energy consumption.
- Heating is the major consumer during stabling hours.
- An empirical correlation between ambient temperature and power drawn is derived.
- The methodology described may also be applied to other urban and main line railways.

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ABSTRACT

Urban rail has widely recognised potential to reduce congestion and air pollution in metropolitan areas, given its high capacity and environmental performance. Nevertheless, growing capacity demands and rising energy costs may call for significant energy efficiency improvements in such systems. Energy consumed by stabled rolling stock has been traditionally overlooked in the scientific literature in favour of analysing traction loads, which generally account for the largest share of this consumption. Thus, this paper presents the methodology and results of an experimental investigation that aimed to assess the energy use of stabled vehicles in the Tyne and Wear Metro system (UK). It is revealed that approximately 11% of the rolling stock's total energy consumption is due to the operation of on-board auxiliaries when stabled, and investigation of these loads is therefore a worthwhile exercise. Heating is responsible for the greatest portion of this energy, and an empirical correlation between ambient temperature and power drawn is given. This could prove useful for a preliminary evaluation of further energy saving measures in this area. Even though this investigation focused on a particular metro system in a relatively cold region, its methodology may also be valid for other urban and main line railways operating in different climate conditions.

1. Introduction

Metropolitan transportation is responsible for about 25% of the CO_2 emissions caused by the transport sector in the European Union (EU) [8], which approximately represents 8% of total greenhouse gas emissions in the EU [12]. Furthermore, high levels of air pollution and congestion are major problems usually associated with urban mobility. Therefore, more efficient, reliable and environmentally friendly transport systems are key in dealing with increasing urbanisation, whilst reducing GHG emissions and enhancing living conditions in urban areas.

Urban rail is well placed to mitigate the impact of the problems associated with urban mobility because of its high capacity, safety, reliability and absence of local emissions [25]. In addition, it typically has lower CO_2 emissions per passenger than competing transportation modes, although this is dependent on passenger load factors and the electricity generation mix [6]. Nevertheless, in a context characterised by rising energy costs and growing capacity demands, and where other modes such as automotive are making significant improvements in their environmental performance, it is critical that urban rail minimises its energy consumption while enhancing its service quality.

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Energy use in railway systems is commonly classified into traction and non-traction loads. The former comprises the power required to operate the rolling stock across the system (including propulsion and on-board auxiliary systems), whereas the latter accounts for the energy utilised at stations, depots and other facilities in the system. On average, traction energy consumption generally represents between 70% and 90% of the total energy consumption in urban rail systems, of which around 20% is due to on-board auxiliaries [10]. Hence, the majority of proposals to reduce energy consumption in railway systems have focused on the traction system itself, primarily by using regenerative braking [9], applying energy-efficient driving strategies [7], or improving the propulsion chain efficiency [13]. In turn, there has been relatively less focus on the on-board auxiliary systems.

Auxiliary power is required for two main purposes: control and cooling of vehicle systems, and comfort functions – these include heating, ventilation and air-conditioning (HVAC), lighting and information systems. HVAC equipment is generally responsible for the most significant part of this consumption, with a clear dependency on climate conditions. In the Oslo metro for instance, heating accounts for 78% of the auxiliary consumption, with 3% for control systems and the remaining 19% for other auxiliaries such as lighting and air supply [22]. This corresponds to heating accounting for 28% of the vehicle consumption overall. In addition, variations of up to 38% in the total energy consumption were found between summer and winter months for a fleet of regional trains operating in Sweden [3].

On-board auxiliary systems remain partially or fully operative while trains are stabled in sidings or depots. This is principally to facilitate cleaning operations and to prevent damage to vulnerable components, for example any condensation in the air supply system freezing overnight. Furthermore, it is necessary to reach the desired comfort conditions (such as temperature) in vehicles before they enter service. Therefore, the operation of on-board auxiliaries while trains are out of service may account for a significant portion of the total energy consumption – for example general studies of Central and Northern Europe main line services estimated energy consumption of stabled trains to be around 10–15% of the system's total energy consumption [18,24]. The scarcity of information and experimental data published in the academic literature – particularly for the case of urban rail – seems to call for more thorough investigations.

The main purpose of this paper is therefore to develop a deeper understanding and promote awareness of power consumed by rail vehicles while stabled. To achieve this, the outcomes of an experimental investigation aimed at assessing the energy use of stabled vehicles in the Tyne and Wear Metro (UK) are presented. The paper starts by briefly describing the Metro system, continues by explaining the research methodology and concludes by showing and discussing the main energy consumption results obtained for a single vehicle while stabled. Special emphasis is placed on examining the influence of ambient temperature upon the on-board auxiliaries' energy consumption. Although this paper focuses on an urban rail system as the specific case study, it is intended that the methodology described could be applied to all rail systems.

2. Introduction to the Tyne and Wear Metro system

2.1. General description and climate conditions

The Tyne and Wear (T&W) Metro is a light rail system centred on Newcastle upon Tyne in the north-east of England. First opened in 1980 as a 54 km route (of which 41 km had been adapted from existing heavy-rail tracks), currently the T&W Metro consists of a 78 km network that links the cities of Sunderland, Gateshead and Newcastle with the local airport and coastal regions. It is the second largest urban rail system in the UK (after London Underground), and the only one powered by an overhead 1500 V DC supply network. Further details on the T&W Metro can be found in Refs. [11,16,20] and [19].

The original rolling stock remains in service today, although it was refurbished between 1995 and 2000, and is currently undergoing life extension work to run until the mid-2020s. The fleet consists of ninety identical 28 m long twin-section articulated Metrocars built by Metro-Cammell; there are 68 seats, although around 300 passengers may be carried under crush load conditions. A single articulated Metrocar is carried on three two-axle bogies, with each outer bogie powered by a 185 kW series-wound DC monomotor, resistance-controlled by an air/oil camshaft. Braking is a combination of rheostatic and spring applied/air released friction brakes. The typical train configuration consists of two Metrocars, although single unit operation is also possible.

Fig. 1 illustrates the monthly average minimum and maximum temperatures in the Newcastle-upon-Tyne area for the period 1981–2010, together with the 20th and 80th percentiles [17]. The maximum average temperatures rarely exceed 19 °C, whereas the minimum temperatures are normally above 0 °C. Therefore, it is likely that heating is required in rolling stock throughout the whole year, whereas cooling will normally be unnecessary.

2.2. Vehicle auxiliary systems

The Metrocar's auxiliaries basically comprise: heating, ventilation, air compressor, lighting and control systems.

Heating is primarily by waste heat recovery; i.e. warm air is ducted to the seat plinths from traction and braking resistors. When required to reach the target comfort temperature (nominally 21 °C), this is complemented by two 15 kW auxiliary heaters (on/off regulation), which are directly connected to the 1500 V DC supply. Metrocars are not equipped with any active cooling system. Instead, the airflow from the resistors is automatically reversed when the saloon temperature exceeds the target point, thus helping to ventilate the train. Additionally, natural ventilation is possible via passenger-operated hopper windows.

The air compressor, which drives subsystems such as door actuators, air suspension and friction brakes, is directly linked to the 1500 V DC supply. Moreover, a motor alternator (MA) set converts 1500 V DC power into 415 V AC power, primarily for lighting and ventilation. The MA set is also used, via a transformer and rectifier, to charge batteries that feed emergency systems (e.g. emergency

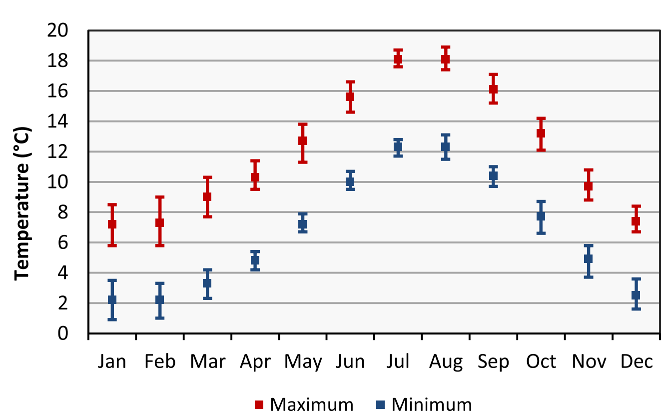

Fig. 1. Average monthly maximum and minimum temperatures in the Newcastle-upon-Tyne area.