Energy and Buildings 125 (2016) 287–297

Contents lists available at ScienceDirect

Energy and Buildings

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

Energy consumption of escalators in low traffic environment

Semen Uimonen[a,*], Toni Tukia[a], Marja-Liisa Siikonen[b], Dirk Lange[c], Claudio Donghi[d], Xiao Liang Cai[e], Hannu Nousu[b], Harri Hakala[b], Matti Lehtonen[a]

[a] Department of Electrical Engineering and Automation, Aalto University School of Electrical Engineering, P.O. Box 13000, 00076 Aalto, Espoo, Finland
[b] KONE Corporation, KONE Oyj, Keilasatama 3, P.O. Box 7, Espoo 02150, Finland
[c] KONE Corporation, KONE GmbH, Ruhrallee 165, 45136 Essen, Germany
[d] KONE Corporation, KONE Industrial S.p.A, Via Figino 41, 20016 Pero, Mi, Italy
[e] KONE Corporation, KONE China Factory NO.88 Middle Gu Cheng Road, Yushan Town, Kunshan, Jiangsu, PR China

ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 22 March 2016
Accepted 7 May 2016
Available online 13 May 2016

Keywords:
Escalators
Energy consumption
Intermittent-operating escalators
People flow
Load profile
Error compensation

ABSTRACT

Lack of information on energy consumption patterns of intermittent-operating escalators and unawareness of building owners of potential energy savings constitute the main obstacles for the penetration of energy-efficient escalator technology. Even though intermittent operation provides large energy savings in low passenger traffic, little research has been devoted to analyzing the composition of total energy consumption in these situations. This paper presents observations and data gathered during long-term energy measurements of an intermittent-operating escalator pair (one upwards, one downwards operating), equipped with reduced speed and stop & go modes, installed in a store in the Helsinki area.

Energy consumption measurements were performed concurrently with people counting. The effect of passengers walking on the step band on daily energy consumption was calculated by relying on the people counting sensor data. Additional experiments were conducted by applying different masses to analyze the dependence of energy consumption on the carried load. Finally, the effect of intermittent operation, or speed control with stop & go functionality, on energy consumption was calculated for the escalator pair on the given site. The energy consumption is reduced up to 42% in the upwards running escalator and 52% in the downwards running escalator compared to a continuously running escalator with the same operating hours. The study concludes that the power consumption profiles of the intermittent-operating escalator pair highly depend on the characteristics of the people flow, mainly the consistency of the people flow.

1. Introduction

An escalator is a moving staircase for transporting people between floors of a building. It is generally agreed that an escalator is the most efficient mean to move large numbers of people between floors [1]. From the energy efficiency perspective, escalators received limited attention in the past. It has always been discussed alongside lift energy efficiency and has, therefore, remained in the background. Little information is available regarding the number of escalator installations in recent years. According to Patrão et al. [2], European Lift Association (ELA) statistics estimate that about 75 000 escalators were installed in EU-27 by year 2010, and about 3500 new ones are commissioned every year. In North America, there are approximately 35 000 escalators in the U.S. and 9000 in Canada [3]. National Elevator Industry, Inc also states that the average number of people carried per day per escalator is 12 000, which is approximately 105 billion passengers per year in the U.S. alone. The number of escalators is expected to increase worldwide. To this day, there are multiple installations that use old technologies without energy saving features during the whole time of operation. Energy efficient technologies and features are able to greatly reduce electricity consumption in these types of installations and help to achieve the goals of the European Union [4] in energy efficiency. Among main barriers for penetration of these technologies into escalators and lifts is the lack of information on energy consumption patterns. Consequently, the profitability of such energy saving measures is assessed incorrectly by the building owners [5].

* Corresponding author.
E-mail addresses: semen.uimonen@aalto.fi (S. Uimonen), toni.tukia@aalto.f (T. Tukia), marja-liisa.siikonen@kone.com (M.-L. Siikonen), dirk.lange@kone.com (D. Lange), claudio.donghi@kone.com (C. Donghi), xiaoliang.cai@kone.com (X.L. Cai), hannu.nousu@kone.com (H. Nousu), harri.hakala@kone.com (H. Hakala), matti.lehtonen@aalto.fi (M. Lehtonen).

http://dx.doi.org/10.1016/j.enbuild.2016.05.018
0378-7788/

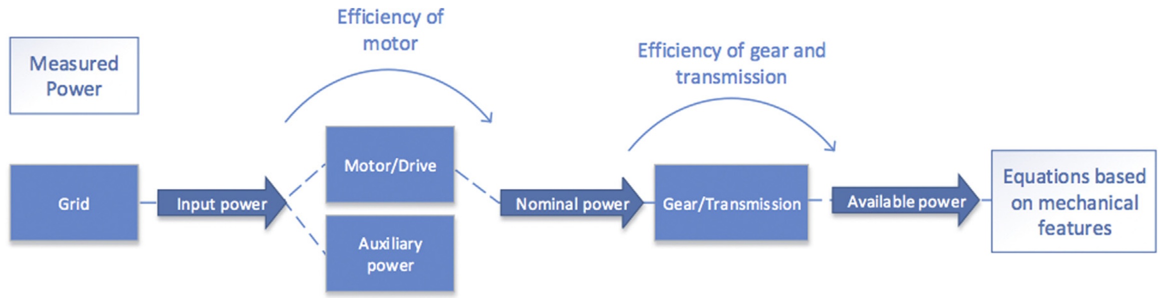

Fig. 1. Available power in comparison to the input power.

The objective of this study is to obtain the energy consumption patterns of a widely used commercial escalator pair and to assess the energy savings provided by intermittent operation, i.e., speed control. In addition, this paper analyzes the effect of passenger traffic characteristics, mainly mass, consistency and speed. The selected escalator pair is merely a single example of the diversity of possible installations, which could vary in height, width and installed electrical equipment, applications and passenger load. Nevertheless, the chosen escalator type presents the most common setup in terms of height, nominal speed and passenger volume sold on the escalator market.

Section 2 describes previous studies conducted in the field of escalator energy saving technology and theoretical background. Section 3 shows the approach taken to perform necessary measurements: the equipment used, measured appliances on site and methods of reliability assessment of gathered data. The obtained average power consumption curves, corresponding people flow data, further mass experiment, effects of walking on daily consumption and energy saving effects of speed control are presented in Section 4. Section 5 discusses the necessity of additional studies for further improving energy efficiency of intermittent-operating escalators. Conclusions drawn from the whole paper are presented in Section 6.

2. Background

Energy consumption of an escalator depends on factors such as the electrical and mechanical design, control and operation means, passenger characteristics and quality of maintenance [6]. One of the most broadly used technologies in new installations is the Variable Speed Drive (VSD), which enables intermittent operation by means of speed control. Alternative solutions include Variable Voltage Constant Speed Drive (VVC), which uses a VVC controller to reduce the energy by controlling the motor voltage and improving motor power factor at the times fewer people are using the escalator while the speed is kept constant [7]. Similarly, a Star/Delta controller could be installed to increase energy efficiency in low load conditions. Other popular solutions include regenerative solutions with Power Feedback Unit (PFU), which allows regenerating power from a downwards running escalator when its load exceeds a certain amount. However, asynchronous squirrel cage induction motors are able to provide the capability to feedback generated energy without any means of PFU and regenerative devices [8]. Of the above, this paper focuses on the benefits of escalator speed control.

For escalator speed control, the following options are commonly available:

- Stop & go operation, mode where escalator stops running when it is not in use.
- Reduced speed by means of inverter control. This feature allows to run the escalator at reduced speed while there are no passengers on the step band. Speed reduction usually reduces speed up to 50% of the nominal.

2.1. Previous research

Among previous studies, the most eminent is the campaign in Europe [5], targeted at the improvement of the energy performance of lifts and escalators in the tertiary sector buildings. In the EU, around 75% of escalators are installed in commercial buildings and the remaining 25% in the public transportation areas [2]. At the same time, escalators installed in public transportation areas consume up to 75% more power, due to larger amount of working hours. The study has also assumed that 30% of escalators are equipped with a Variable Speed Drive (VSD). A potential reduction in electricity consumption by means of using best available technologies was estimated to be around 28% in Europe [8].

Previous studies on the relation between escalator power consumption and pedestrian flow, which served as a basis for further analysis of the data acquired in this study, are research papers by Carrillo et al. [9], Kuutti et al. [10] and Al-Sharif [6,11]. The paper by Carrillo et al. [9] focused on energy savings provided by two-speed control. In two-speed control, the speed of an escalator is reduced when a certain period of time has passed since last passenger detection. Effect of the change in the time delay on the consumption of the upwards running escalator is also presented in their publication. In Kuutti et al. [10], energy measurements of a fixed-speed and an intermittent-operating escalator were conducted for comparison.

In studies [6,11], the total energy consumption of an escalator has been divided into fixed losses and variable losses. Fixed losses are the result of power drawn by the escalator when no passengers are travelling on it. Variable losses add up on top of the fixed losses and depend on such factors as the number of daily passengers, their average mass and the rise of the escalator. Both fixed and variable losses are influenced by the efficiency of the motor, the efficiency of the gear and friction in the moving components.

2.2. Theoretical background

The differentiation between fixed and variable power consumption is, indeed, a comfortable approach to differentiate energy consumption of an escalator. However, fixed power consumption is not entirely fixed. It varies in time with the changing load, as the efficiency of an asynchronous motor alters depending on the load, which is far from nominal in low traffic environment. Moreover, the frictional coefficients vary during the day and the lifetime of the escalator system. Therefore, this paper discusses an approach with less ambiguity in defining power consumption. In the approach, the energy consumption consists of energy used for transporting variable mass on the step band, energy required to move the mechanical system and energy required for lighting and other auxiliary equipment. The approach is mainly presented for background