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Explicit method to predict annual elevator energy consumption in recurring passenger traffic conditions

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ABSTRACT

This paper proposes a method for simple projecting of annual elevator electricity consumption based on short-term energy measurements and identifies challenges in the determination of actual energy consumption based on kWh meter readings. The study also analyzes the impact of the employed elevator technology, building type, and seasonal variations in elevator usage on the calculation of the annual consumption. Thus, the method can be adopted in different regions with varying elevator usage. The approach employs elevator specific daily energy consumptions measured on the prevailing day types. The reliability of the proposed approach was analyzed and the performance compared to actual measured annual consumption and estimates provided by commonly adopted energy efficiency classification schemes, VDI 4707-1:2009 and ISO 25745-2:2015. The results of the monitored office elevator indicated that the proposed method performs generally better than the competing approaches.

1. Introduction

Elevators are perhaps the most visible form of building services. Consequently, they consume energy while transporting passengers between floors. However, the amount of energy consumption is rarely measured, which hinders elevator-related cost analysis and budgeting. Knowing the consumption also enables planning investments targeted at improving the elevator energy efficiency and secures shortest investment payback times. For example, in residential buildings, the annual electricity costs can be so low that investments are unattractive, while office buildings may provide better payback.

Elevators have large differences in energy consumption that result from the installation location, passenger traffic, and used technology [1,2]. On annual level, the elevator energy consumption can be acquired with at least four different approaches:

(1) Permanent installation of a kWh energy meter
(2) Elevator simulators [3–6]
(3) Energy classification schemes

- VDI 4707-1:2009 [7]
- ISO 25745-2:2015 [8]

(4) Day type based prediction methods [9,10]

Installing kWh energy meters certainly seems the most straightforward, reliable method, but it has some challenges related to the desired accuracy and costs, discussed more in Section 2.

Elevator simulation tools are often required to be able to sell an elevator for a certain energy class according to customer demands. After the installation, metering can be used to validate the simulation results. Simulations can provide a suitable level of accuracy but require a considerable amount of background information on the elevator setting and usage. Moreover, simulation tools are typically dedicated to analyzing intraday power consumption [3–6] and are unnecessarily complex for calculating the annual energy consumption. Therefore, simulation tools are excluded from later parts of this paper.

Energy classification schemes enable relatively accurate consumption estimates with high-quality traffic statistics and short-term power consumption measurements during specific running cycles. Unfortunately, the traffic data is seldom available and running cycle tests are difficult to perform during normal working hours, as they necessitate a certain travel cycle up and down,

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obstructing normal elevator usage.

Day type based prediction methods rely on the phenomenon that the passenger traffic is a recurring event. The traffic profiles depend on the building type, and the daily consumption is strongly related to the amount of traffic, as explained in Section 2.1.1. Typically, the weekly profile is presumed to repeat throughout the year, as supported by Fig. 1. However, in reality, seasonal differences in passenger traffic cause some variation between the weeks. Nevertheless, a complete year can be considered highly repetitive without major changes, e.g., in the occupancy rate.

This paper proposes a prediction method which utilizes the recurring weekly profile to calculate the annual energy consumption of an elevator. Instead of relying on unreliable day and building type specific ratios, presented in Section 2.1.1, the proposed method involves straightforward measuring of energy consumption over the most significant day types. The measured daily consumptions are then assumed to repeat each week for the given year. Additionally, the method can also incorporate the impact of seasonal variation in elevator usage.

The previous approaches and the proposed methods are presented in Section 2 with the introduction of the employed metering equipment. Section 3 provides the actual logged results from the monitored site and presents the annual consumption projections based on cumulated energy consumption data. In addition, the performance of the proposed methods is compared to the measured annual consumption and to the estimates provided by the VDI 4707-1 guideline and the ISO 25745-2 standard. Section 4 discusses the applicability of the proposed methods, and Section 5 concludes the main findings and suggests future research.

2. Methods

The aim of the proposed model is to provide a sufficiently accurate prediction of the annual electricity consumption of an elevator or an elevator group by measuring the consumption for only a few days or weeks with a portable high-accuracy energy meter. In comparison to earlier estimation approaches, the model requires less background data on the elevator traffic, elevator technology and dimensions of the building. Furthermore, adopting the proposed method reduces the need to invest in additional energy consumption monitoring technology in buildings with repeating people flows. The savings can be achieved on multiple levels, including:

- Electrical design phase (less equipment)
- Data handling (logging interface, storage, analysis)
- Metering equipment (kWh meter, current transformers)
- Enclosure equipment (size, wiring)
- Installation costs (electricians)

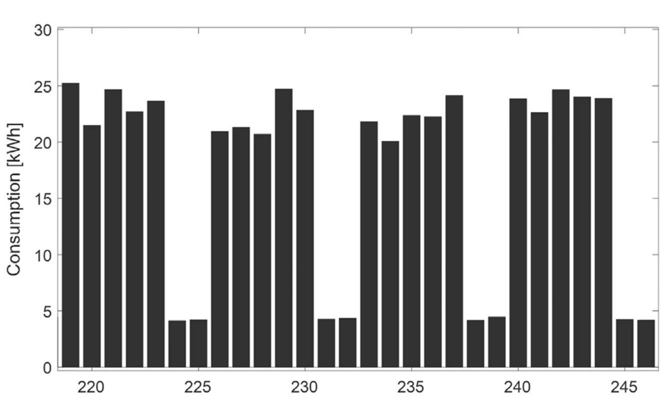

Fig. 1. Daily electricity consumption of an elevator in an office building during four weeks. The low bars represent weekends (Saturday and Sunday).

The ever more detailed submetering also creates reliability issues, as the accuracy of common meters reduces with less measured flow. Especially, cost effective long-term monitoring of appliances with peaking power is a challenge. In elevators, the high currents during acceleration require the use of current transformers, which, on the other hand, are the most significant error source in low-demand standby, as the electric current may fall under 5% of the nominal primary current of the CT. In this current region, the specifications of the classification standard are less demanding or not even expected to apply [11]. The portable high-end energy meters often utilize specially designed CTs and algorithms to diminish these errors found in typical cost friendly kWh metering systems which utilize common transformers.

Nonetheless, the method also benefits sites with metering systems by providing an easy method to predict the annual consumption and its changes. Consequently, a change in the energy consumption trend can also signal a change in the number of people utilizing the building or in the way the building is occupied, which enables better design and faster reorganization of other building services. On the other hand, a shift in the energy consumption trend may also provide crucial information on acute maintenance needs.

2.1. Methods for annual consumption prediction based on day type

2.1.1. Earlier approaches

The electricity consumption of an elevator is mainly related to stationary power demand and running energy demand. The relation of these two parts of consumption is highly affected by the passenger traffic. Considering a typical building, the amount of people in the building and their intraday movements change by day type. In [10], eight different day types have been proposed:

(1) Mondays to Thursdays (normal working period)
(2) Fridays (normal working period)
(3) Saturdays (normal working period)
(4) Sundays (normal working period)
(5) Mondays to Thursdays (holiday season)
(6) Fridays (holiday season)
(7) Saturdays (holiday season)
(8) Sundays (holiday season)

A simpler approach separating only working and non-working days from each other may also be sufficient [9,10].

With the segmentation of similar day types into categories 1… n, the total annual consumption can be calculated as follows [10]:

$$E_{\text{annual}} = \sum_{i=1}^{n} d_i E_i, \tag{1}$$

where d_i is the number of days in a year of the day type i and E_i is the corresponding daily energy consumption. In matrix form, the equation can be presented as

$$E_{\text{annual}} = \begin{bmatrix} d_1 & \dots & d_n \end{bmatrix} \begin{bmatrix} E_1 \\ \cdots \\ E_n \end{bmatrix}. \tag{2}$$

Dissertation [10] also introduces a more detailed methodology concerning the amount of starts, energy consumption in each operation mode, and other components of energy consumption. Analyzing these parameters is crucial in energy classification

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