Lift Energy Modelling for Green Building Design

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Abstract. Lifts are a relatively minor concern when considering green buildings, yet increasingly they are becoming subject to scrutiny with the drive to net zero. The energy consumption of lifts is a major part of their environmental impact. To reduce that impact, first, we need to improve our understanding and modelling of lift energy consumption. Many attempts have been made to define ways of calculating lift energy consumption. Some are so simplistic that their results are of questionable value. Others are so sophisticated that their widespread application is unlikely other than to specific products. This paper addresses why lift energy modelling is complex and discusses the factors which are most significant. Models based on calculation and traffic simulation are considered. The modelling method proposed addresses the need for considering passenger demand and allows for simple measurement and verification.

1 INTRODUCTION

In 1994 Peters presented a paper at the CIBSE National Conference titled *Green Lifts?* [1] posing the questions, “is there such a thing as a green lift”, and “can we design a lift system that delivers good passenger service at an acceptable cost while incurring minimum environmental impact?”. At the time there was little interest, but today these questions seem far more relevant and important; although lifts are generally considered a minor contributor to the environmental impact of a building, they are increasingly subject to scrutiny.

The environmental impact of lifts is likely to become even more important as the world builds up, which, perhaps surprisingly is the recommendation of some of the environmental lobby. In “There is no planet B” [2] Berners-Lee writes “The ideal city is compact and easy to get around. The buildings are tall and generally close together”.

2 THE ENVIRONMENTAL IMPACTS OF LIFTS

To assess the environmental impact of vertical transportation systems, we first need to have some measure of environmental burdens. A Life Cycle Assessment or Analysis (LCA) is defined as the systematic analysis of the potential environmental impacts of products or services during their entire life cycle. It considers components such as:

- resource extraction of materials for manufacture
- manufacture and installation
- use of the product
- re-cycling and re-use
- waste
- transportation at all stages

A lift LCA presented in 1994 [1] was based on a 4-car group installed in London with a 30-year life and one major refurbishment at 15 years. The analysis suggested that the dominating environmental burdens in the life of this hypothetical lift system were the non-renewable resources depleted, the waste created, and the emissions generated through the production of electricity for the operation of the lifts while in use.

In 2013, Lorente presented her thesis titled *Life Cycle Analysis and Energy Modelling of Lifts* [3]. An extract from her LCA discussion, *Environmental Impacts of Lifts* was presented at the Lift & Escalator Symposium in 2014 [4]. Lorente presents results for a category 3 (medium usage) lift which is reproduced in Figure 1. The Eco 99 scale is an attempt to weigh the importance of environmental impacts based on human health, ecosystem quality and resources [5]. The energy mix assumed is based on 2008 data.

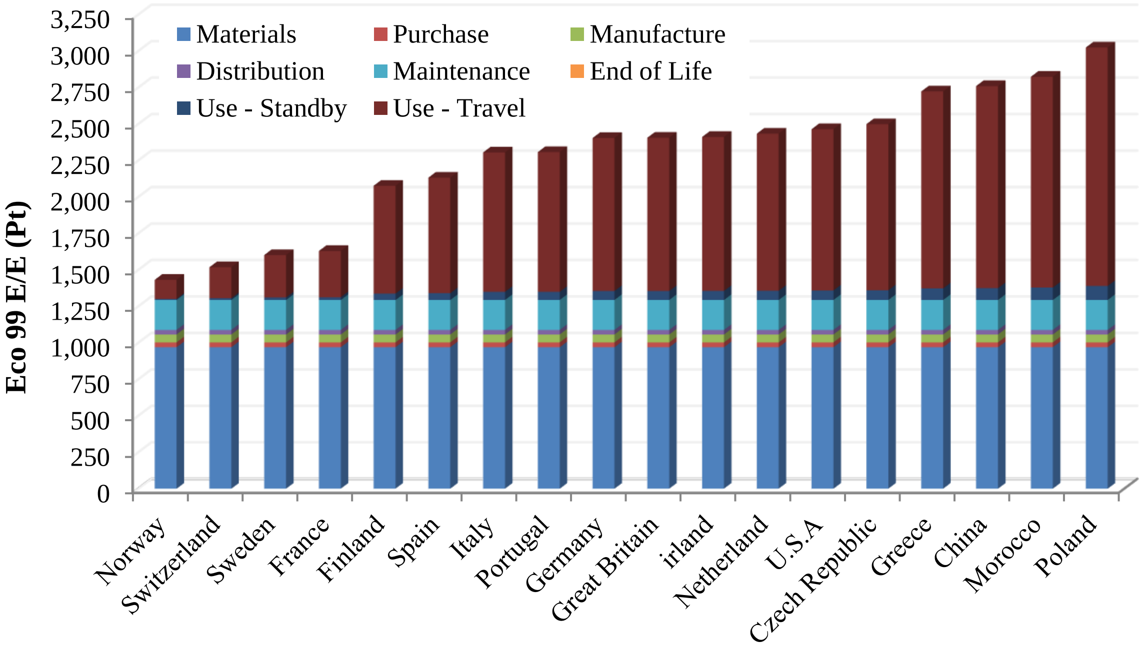


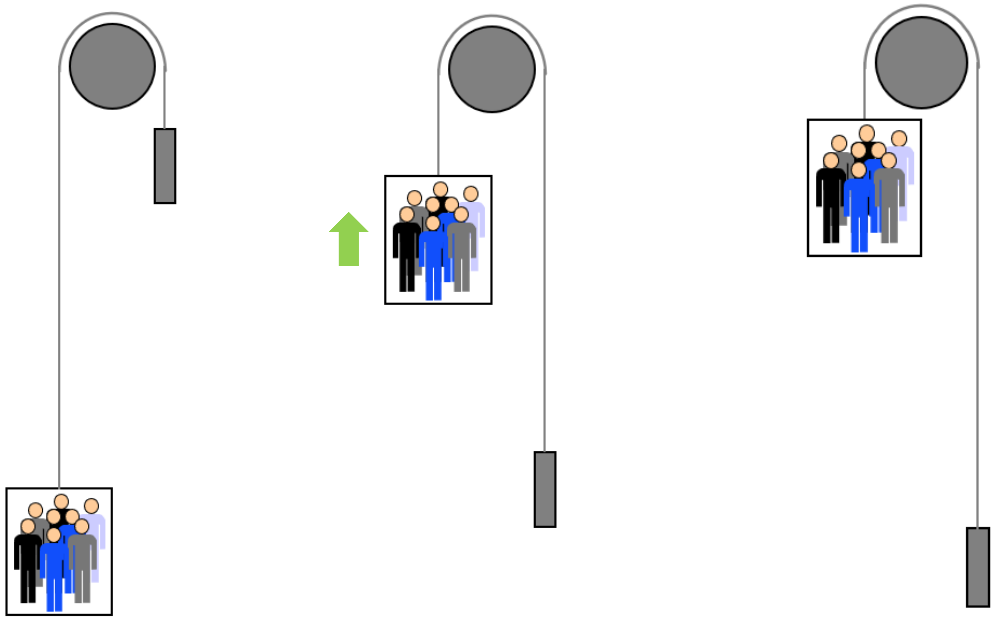
Figure 1 Environmental Impact results (630kg gearless traction) for the usage category 3, installed in different countries

Lorente states that the life expected for the lift and/or its components plays a decisive role in the final environmental impact of the lift. Indeed, for an occasionally used, economy lift with a short life, imported into a country with an "environmentally friendly" energy mix, the dominating environmental burdens are not going to arise from the electricity consumed in use. But they are still significant.

3 HOW A LIFT USES ENERGY IN SERVICE

3.1 The ideal scenario

Al-Sharif, Peters, and Smith [6] explain that in an ideal world, with no friction and losses, energy is never consumed by a lift, it is borrowed and then returned. Consider the morning in an office building with a full car travelling up from the ground floor. Part of the electrical energy supplied is converted into kinetic energy as the lift accelerates and is given back when the lift decelerates. The other part is given to the passengers as potential energy, see Figure 2. The potential energy is returned when the passengers travel back to the ground floor, see Figure 3.

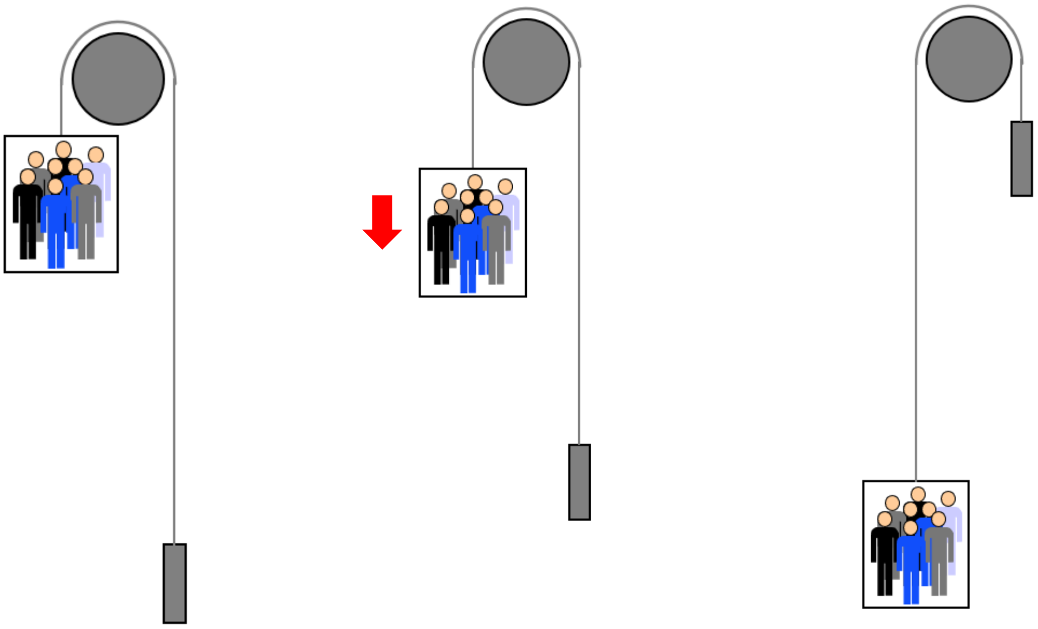


Full lift at ground floor ready to travel up

Lift travelling up, electrical energy converted to kinetic energy and potential energy

Journey complete, kinematic energy reclaimed, passengers retain potential energy

Figure 2 Example ideal lift energy transfer for up journey



Full lift at upper floor ready to travel down

Lift travelling down, electrical energy converted to kinetic energy and potential energy returned

Journey complete, kinetic energy reclaimed; all passenger potential energy returned

Figure 3 Example ideal lift energy transfer for down journey

3.2 A real scenario

Consider an up journey with a measured speed profile as given in Figure 4.

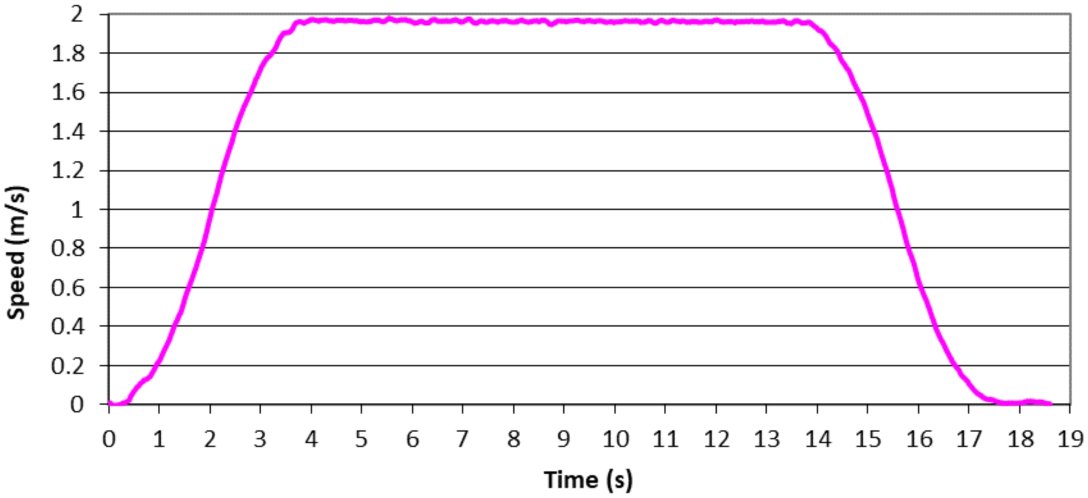


Figure 4 Measured speed profile

The energy consumption of a loaded car travelling up was measured as shown in Figure 5 [6]. Travelling up, the lift reaches full speed after approximately 4 seconds. Once at full speed, it draws a relatively constant 30 kW until it starts to decelerate. The energy consumed is 0.11 kWh. The energy consumed by the same loaded car travelling down was measured as shown in Figure 6. As this is a regenerative drive, during part of the trip energy is being reclaimed, a total of 0.04 kWh. Unlike the ideal scenario represented by Figure 2 and Figure 3, we have losses; to transport these passengers up and then down the building cost us 0.11 kWh – 0.04 kWh = 0.07 kWh.

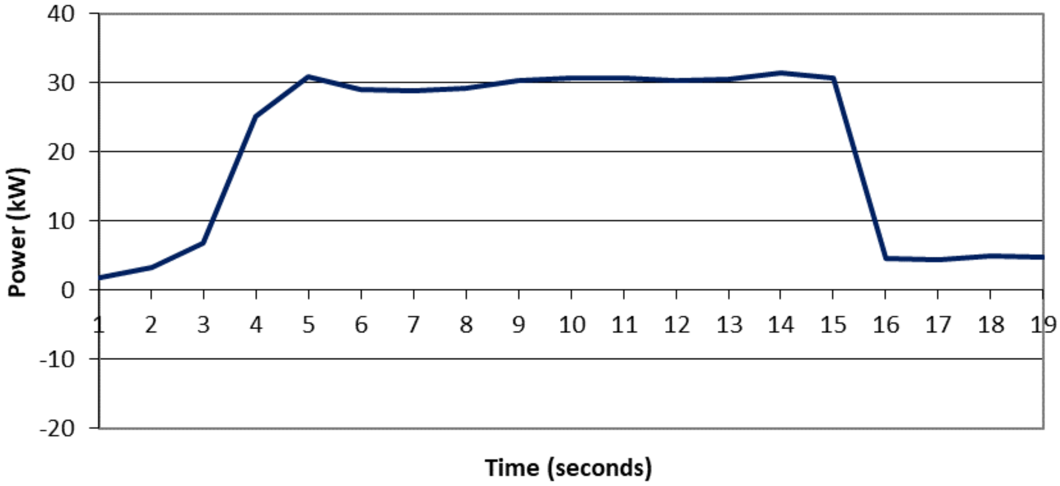


Figure 5 Energy consumption of loaded car travelling up

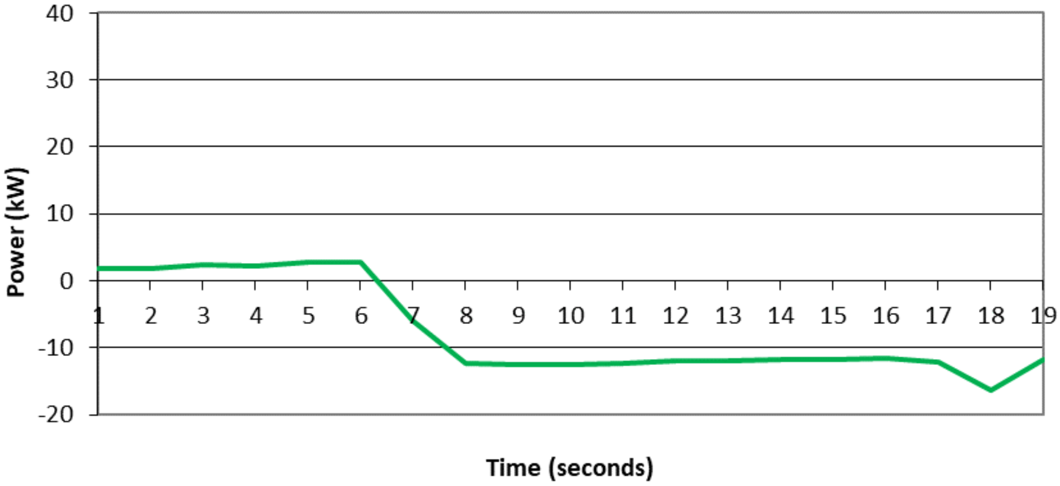


Figure 6 Energy consumption of loaded car travelling down

3.3 Four quadrant operation

A lift is said to operate in four quadrants, as shown in Figure 7. When a lift leaves the ground floor full of passengers, it is motoring, requiring predominantly positive torque (T) in a positive direction. As passengers are dropped off up the building, the counterweight becomes heavier than the lift, so the motor is providing predominantly negative torque in a positive direction. Similarly for a journey down the building, in a negative direction, the motor can be required to deliver both positive and negative torque.

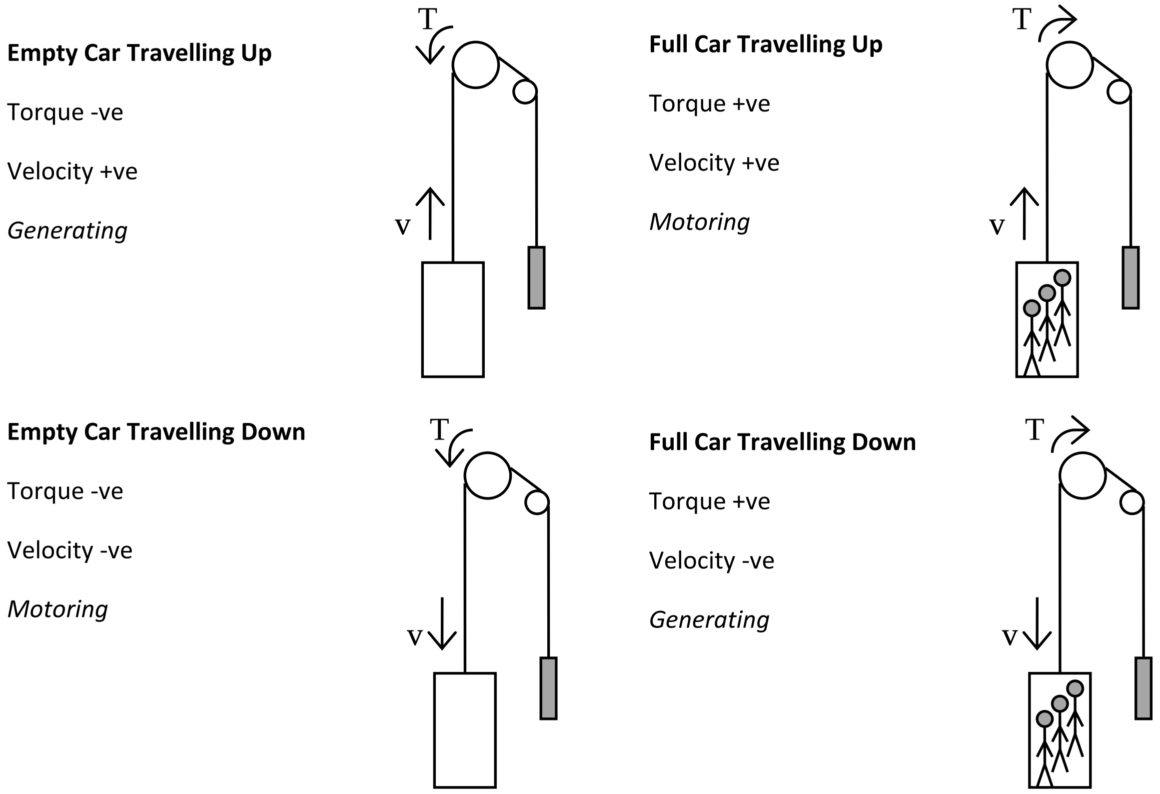


Figure 7 Four quadrant operation of a lift drive

To capture the energy consumption across these four quadrants, Al-Sharif, Peters, and Smith [6] measured the energy consumption across a range of loading in the up and down directions, see Figure

8. Note that when the car is part loaded the mass of the car plus passengers is closer to the mass of the counterweight; in this case, the energy consumption when up to full speed is less, and the peaks (and troughs) at the beginning (and end) of the trip are more marked as the kinetic energy component is more dominant.

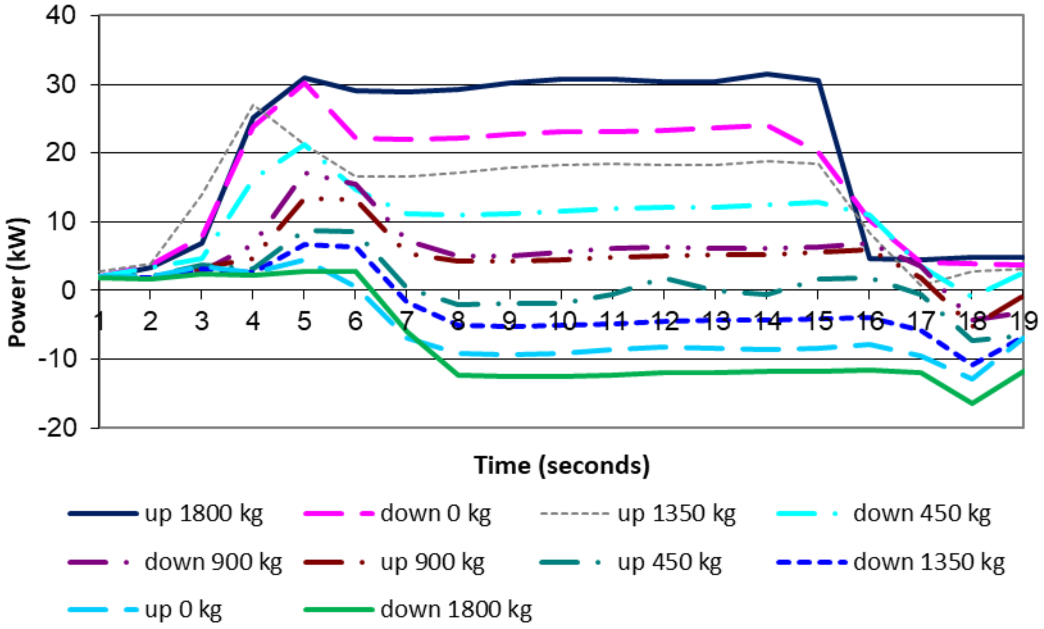


Figure 8 Energy consumption of car travelling up and down for a range of loads

3.4 Non regenerative drives

If the lift drive is not regenerative, then no energy is reclaimed. The best-case equivalent of this is Figure 9. To transport these passengers up and then down the building now cost us 0.11 kWh + 0.00 kWh = 0.11 kWh rather than 0.07 kWh.

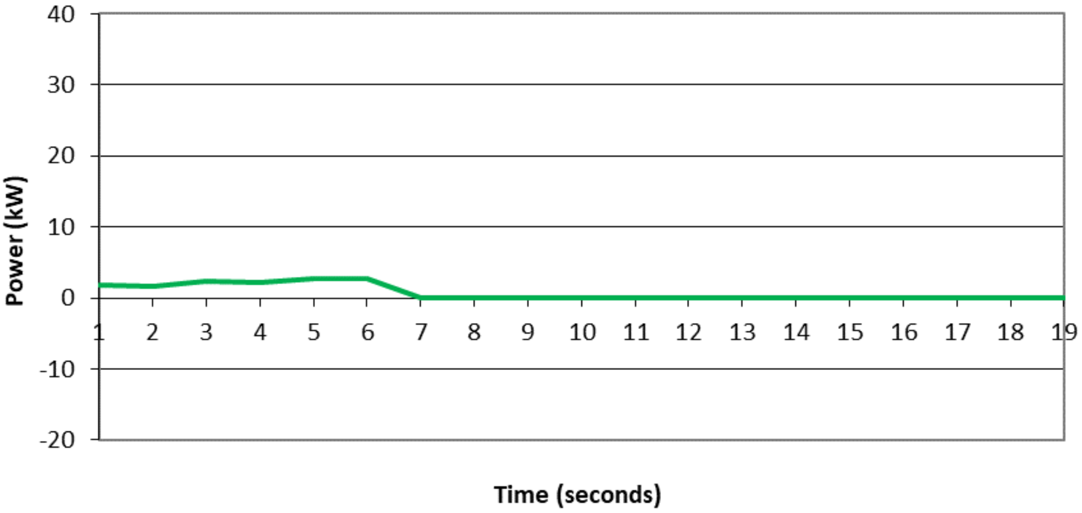


Figure 9 Energy consumption of loaded car travelling down without regeneration

3.5 Energy consumption when idle

Most of the time a lift is idle because there are no calls to serve, or passengers are loading/unloading. The power consumption while idle is crucial. Our measurements have ranged from under 100W to over 2 kW.

3.6 Passenger demand

Two identical lift groups in two identical buildings will consume different amounts of energy. This is because it is the passengers who create the calls which are allocated by the dispatcher to the lift, resulting in individual lift journeys carrying different numbers of people. The number of trips, direction and car loading for the trips is determined by the passenger demand and the dispatcher allocating individual passengers to lifts.

4 ENERGY MODELS

Many attempts have been made to define ways of calculating lift energy consumption. A comprehensive review of these is provided by Lorente in her Doctoral Thesis [3]. She reviews methods listed as:

1. Schroeder
2. Doolard
3. CIBSE Guide D Version 2005 & 2010
4. Al-Sharif-Peters-Smith
5. Barney (a) and (b)
6. Hong Kong Code of Practice
7. Swiss Study
8. Comunidad de Madrid
9. VDI 4707 Part 1
10. VDI 4707 Part 2
11. ISO TC178 WG10 (ISO/FDIS 25 745 -1) – First Draft
12. ISO TC178 WG10 (ISO/FDIS 25 745 -1) – Second Draft
13. E4 Project
14. Lindegger
15. Kone
16. Empirical calculation

Lorente comments that some methodologies make their assessment based on a measurement or calculation process including a single round trip (2, 5a, 6, 8). They are only appropriate for making general recommendations. Other methods (1, 3, 7, 9, 10, 11, 12, 13, 14) aim at rating the performance of the product operating in a certain building; this can be done in a simplified manner or by considering usage patterns or usage category tables.

For example, the Schroeder method (1), proposes an energy calculation based on the formulae:

$$E_d = \frac{R \ \times ST \ \times TP}{3600}$$

Where E_d is the daily energy consumed (kWh/day), R is the motor rating (kW) and ST is the number of starts per day.

CIBSE Guide D (2000) compared the Doolard (2), and Schroeder (1) methods, concluding that they were inconsistent by almost a factor of two; the simplifications required to reduce the energy estimate to a simple method yield only rule-of-thumb results when it comes to energy consumption.

The empirical calculations (16) reviewed were based on a survey of lift consumption collected in conjunction with a questionnaire asking a variety of technical and operational questions. An equation was developed which linked the energy use to the lift drive technology and building size. The authors acknowledge that the formulae will not work other than for the buildings surveyed.

Improving on these methods, Barney and Lorente ran thousands of simulations [7] to build formulae and tables which are claimed [8] to be the most accurate public domain energy model. They are probably correct. The work is now applied in ISO 25745-2: 2015 [9].

Nevertheless, the most accurate methods (4, 5b, 15) recognize the importance of traffic and passenger handling strategies, linking their models directly with traffic simulation programs.

The model developed by Al-Sharif, Peters, and Smith [6] is acknowledged by Lorente as the most accurate model available [3]. It models every passenger journey and corresponding lift trip such that the energy consumed can be calculated on a trip-by-trip basis. A mathematical model of the lift energy consumption was developed which could be calibrated to a specific installation, for example, the measurements given in Figure 8, after calibration yield a set of power consumption curves for all four quadrants, as illustrated in Figure 10. The mathematical model then allows for any trip length and car loading, up and down. This trip-based model will provide the most accurate results if calibrated correctly and if the traffic is known. It is patented by the client it was developed for [10] so is not available in the public domain.

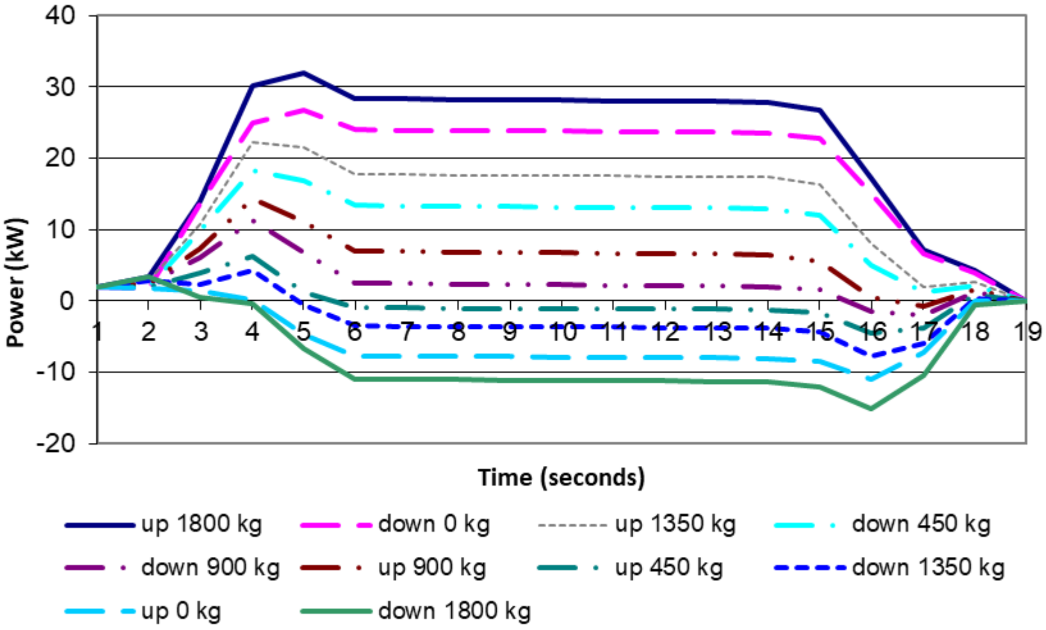


Figure 10 Energy consumption of car travelling up and down for a range of load applying model by Al-Sharif, Peters, and Smith

To offer a simpler model accounting for traffic and passenger handling strategies, one simulation package [11] offers a simple on/off model for the drive at different directions and loads. The equivalent power consumptions curves in Figure 10 become Figure 11.

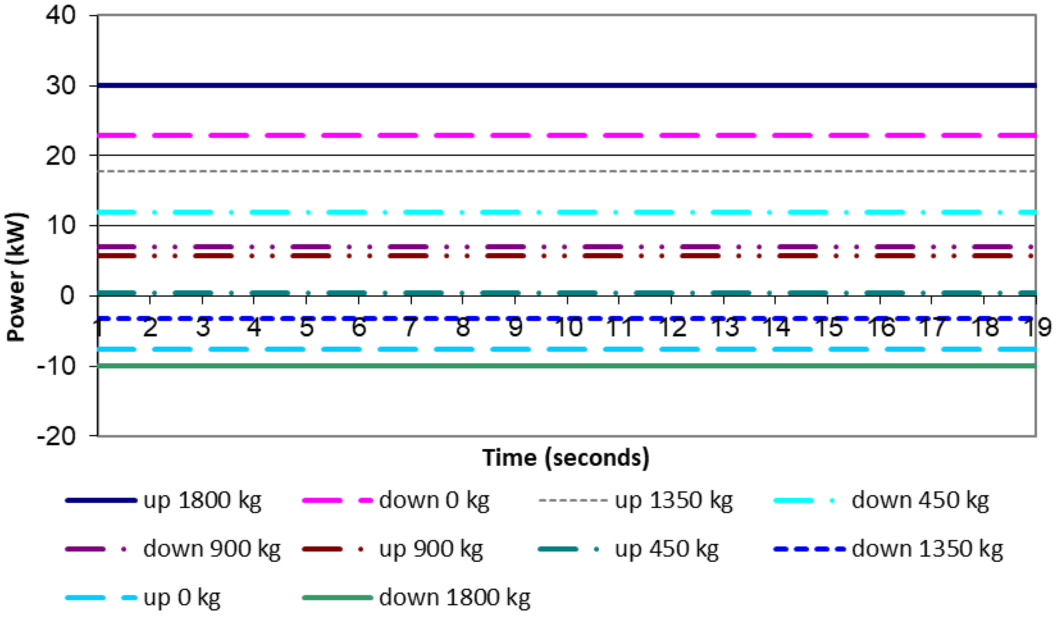


Figure 11 On/off energy consumption model

This approach overestimates the power consumption while the lift is accelerating and decelerating. A better approximation would be, at the beginning of the trip while the lift is accelerating, to draw a straight line from 0 to the power consumption at full speed. And, as the lift is decelerating, another straight line from the power consumption at full speed to 0. The approximation at the beginning of the trip will be an underestimate as we are drawing power to give the system kinetic energy. But that underestimate will be mostly corrected by the overestimate at the end of the trip as the kinetic energy is reclaimed, see Figure 12.

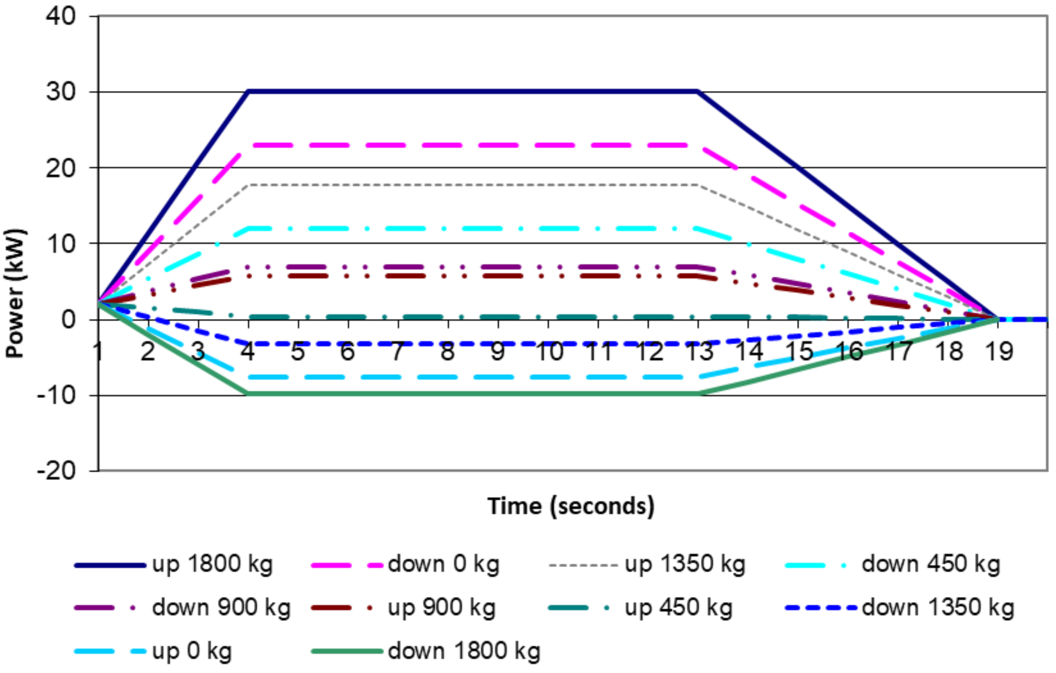


Figure 12 On/off energy consumption model with beginning and end of trip set to 0

This approach provides a trip energy consumption which compares favorably with the more complex model.

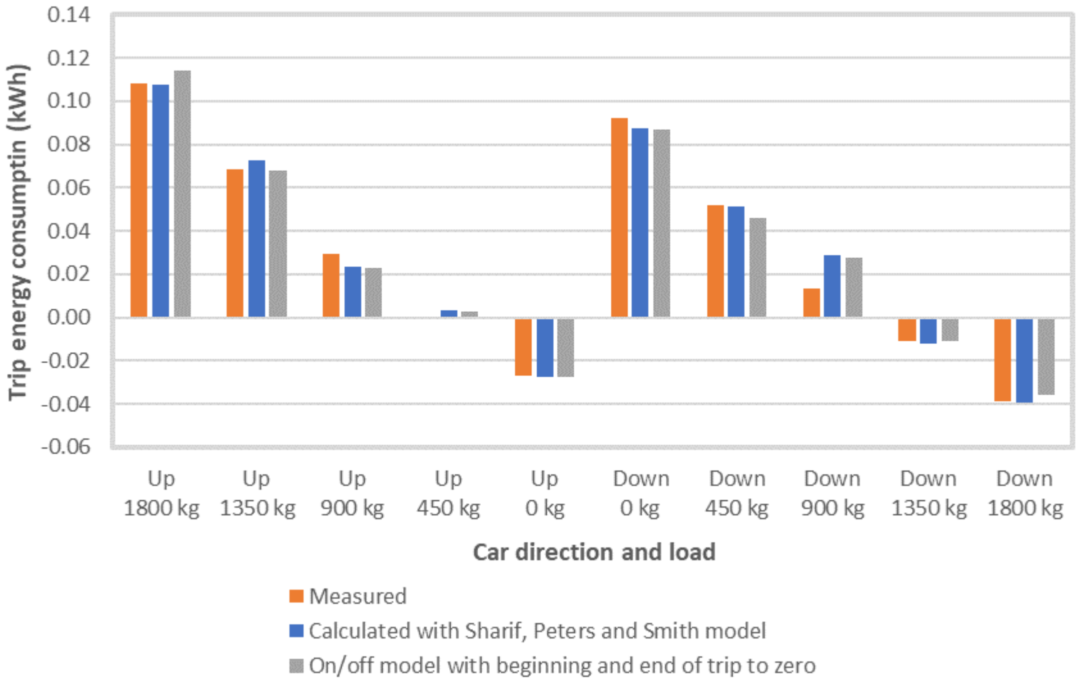


Figure 13 Comparison between measured energy consumption, complex and simplified models

5 CONCLUSIONS

Anyone denying climate change or the importance of reducing our carbon emissions would rightly be considered the modern-day equivalent of a flat-earther. The environmental impact of lifts is not solely due to the energy they consume, but it is a major component. As the climate crisis heightens, buildings get taller and energy prices soar, understanding the energy consumption of lifts becomes increasingly important. If we understand and measure lift energy consumption, we are in a better position to assess improved lift solutions.

Energy modelling of lift systems is complex. There have been excellent attempts to provide formulae and table-based estimates of lift system energy consumption. Without access to a simulation model, the most authoritative of these is presented in ISO 25745-2 [9]. However, without considering all-day passenger demand profiles and the impact of traffic control systems, even the ISO method will only ever offer a rule of thumb estimate of energy consumption.

Applied with simulation, advanced models [6] do offer accurate modelling of individual lift trips. The contribution of this paper is to offer a simpler approach. In the example presented, little accuracy is lost with the proposed simplification. The simpler model proposed in this paper provides a pragmatic, public domain solution which is easier to calibrate and apply in any simulation software.

The final challenge remaining is calibration. For this, the industry needs to collect “big data” on passenger demand and energy consumption and make it available in the public domain. This is technically possible to do and should not need to add major costs if specified early on new projects.

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BIOGRAPHICAL DETAILS

Richard Peters has a degree in Electrical Engineering and a Doctorate for research in Vertical Transportation. He is a director of Peters Research Ltd and a Visiting Professor at the University of Northampton. He has been awarded Fellowship of the Institution of Engineering and Technology, and of the Chartered Institution of Building Services Engineers. Dr Peters is the principal author of Elevate, elevator traffic analysis and simulation software.