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Case study

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A study for improving the energy efficiency of lifts with adjustable counterweighting

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Abstract

This article presents a study of the potential energy efficiency improvement by means of adjusting the lift counterweight. The lift energy consumption in different counterweight setups is studied by employing measured lift traffic and energy consumption data from an office building in Finland. Overall, dimensioning the counterweight based on traffic analysis is one of the fastest and most cost-effective means of improving the energy efficiency of lifts. The results from the building imply, however, that with a relatively constant loading throughout the day, the continuous adjusting of the counterweight provides limited energy savings compared to systems where the counterweight is sized according to the average load. Nevertheless, active adjustment of the counterweight size may provide considerable savings in lift systems if there is a wide variation in the car loading between the hours of the day. Furthermore, reducing the counterweight potentially improves the ISO 25745-2 energy efficiency classification of the lift, thus increasing the product attractiveness in the market.

Practical Application

This article presents practical approaches to analysing the energy consumption of counterbalanced lifts. The modelled results can be used to optimise the mass of the counterweight in order to achieve considerable energy savings in the actual or expected traffic profile.

Keywords

Lift, elevator, counterweight, energy consumption, instantaneous power, traffic profile, optimisation, energy efficiency, energy savings, office building

1. Introduction

The importance of energy efficiency has increased in the lift market. Manufacturers aim at promoting energy-efficient solutions and meeting customer requirements typically based on building energy certificates, such as BREEAM [1] or LEED [2], or energy efficiency classes calculated according to the VDI 4707-1 guideline [3] or the ISO 25745-2 standard [4].

The energy consumption of a lift consists of standby and running energies. The standby consumption can be reduced by, e.g., energy-saving modes and LED lighting [3], [5], [6]. The means to reduce the running energy consumption include smart control and high-efficiency drive and hoisting systems [3], [5], [6]. This current case study analyses the energy efficiency improvements attainable with resizing the counterweight. Prior to [7], written by the authors of this paper, the topic has been briefly discussed, e.g., in [5], [6], [8], [9] and [10].

Figure 1 illustrates a typical traction lift with a counterweight and a 1:1 roping ratio. In addition, it depicts the operation modes depending on the relation of load and counterweight. The direction and the net loading determine the sign (consumption/generation) and the amount of energy related to a start.

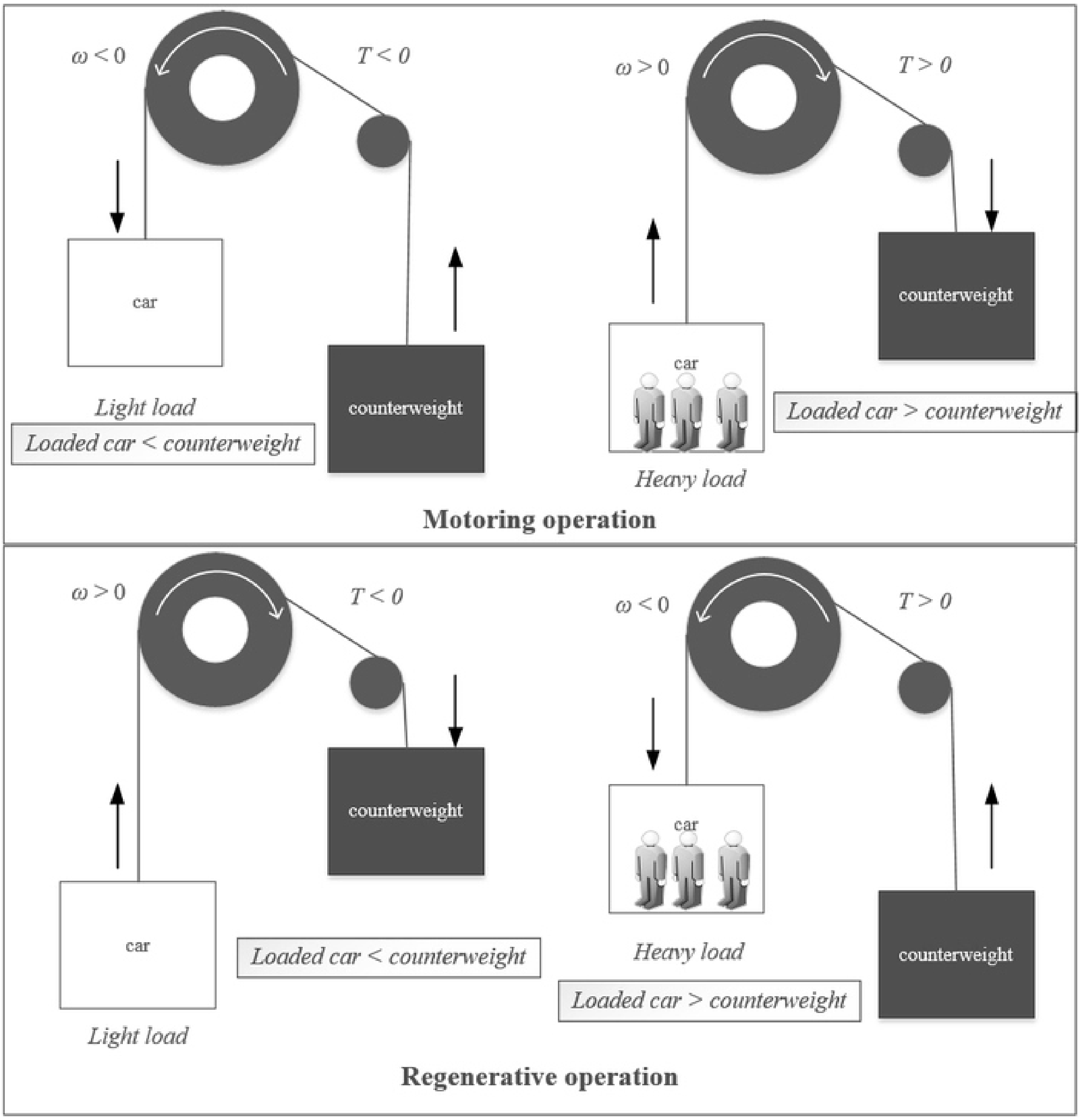

Figure 1 A simplified illustration of a counterbalanced traction lift system and operation modes during starts, adapted from [11]

Adjusting the counterweight size based on the load is uncommon. For example, the ISO 25745-2 standard only considers traction lifts counterbalanced to 30 – 50% of the nominal load, even though the reported average car load in the standard is only between 2 – 19%. Nevertheless, the standard also recognises traction lifts with no counterweight and equates them with hydraulic lifts. This type of lift system typically consumes more energy, as the drive has to raise the weight of the entire car with the passengers. Therefore, counterweights are commonly considered as energy-saving features.

The reason for the relatively high counterweight mass is partially regulatory. For example, in China, the counterweight has to be sized in accordance with a so-called equilibrium coefficient, *K*, with values ranging from 40 to 50% [12]. The coefficient refers to the same counterweight percentage (of nominal load) as the ISO or the VDI approaches. The coefficient is determined from a state where the traction resistances upwards and downwards are equal, i.e., when the car is loaded with the rated load multiplied by the equilibrium coefficient as demonstrated in Figure 2 [12]. This dimensioning has been justified in terms of safety and energy performance, which naturally have to be the highest priority.

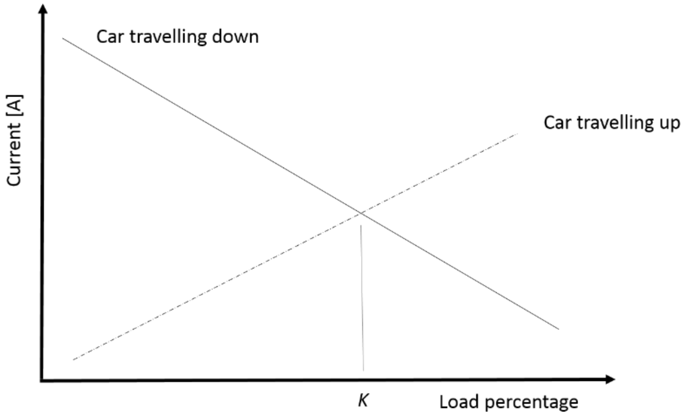

Figure 2 Simplified example of a current-load curve for determining the equilibrium coefficient

Study [9] by So and Wong introduces a system incorporating a power meter and lift traffic data in order to optimise the counterweight size during a specific time period. The optimisation is based on past records and a set of tests performed on the site with various loading scenarios. The study employs a method where the counterweight size ranges between values considered safe by the installation contractor, e.g., between 30 and 60% of the nominal load. In an extensive lift and escalator energy-efficiency study [10] made in Hong Kong, the optimal counterweight ratio was determined to be around 35%. However, this calculation was based on a benchmark parameter *J/kg/m*, which is the amount of energy consumed during a time period divided by the mass of the carried load and the distance the lift covers during that period. Thus, it also includes stationary standby consumption, which creates an accuracy-related issue due to the tests performed on different days with unique traffic patterns. Moreover, as the study applied a safety threshold of 30% for the lowest counterweight ratio, the result of the optimal counterweight ratio of 35% is questionable. Nevertheless, even with the mere 15 percentage unit drop, the reported energy saving was estimated to be over 13% [10]. In [7], we estimated that in most of the high-traffic lift installations, the optimal point is found with relatively light counterweight ratios, e.g., 10% with savings up to 60%. The idea of the light counterweight is also supported by the aforementioned low average car loads given in the ISO standard.

Selecting the counterweight size to match the average load can lead to significant energy savings compared to common counterweight systems, which employ counterweights equal to the mass of the empty car and an additional 40% to 50% of nominal load [5], [7], [8], [9], [10]. In this research article, the aim is to analyse the potential of further developing the counterweight sizing. More specifically, the article has two objectives. First, the focus is on savings achievable with the adjustment of the counterweight mass during the day. In theory, the savings are reached by adjusting the mass of the counterweight based on the predicted loading profile during the next time period, e.g., an hour. Second, the article analyses the effect of resizing the counterweight on the energy-efficiency class provided by ISO 25745-2.

The paper is structured as follows. Section 2 describes the methods employed to gather the travel and energy consumption data. Section 3 presents the empirical model and Section 4 the modelled counterweight resizing results of energy consumption. Section 5 analyses the impact of the counterweight on the energy classification. Section 6 discusses potential further improvements in the adjustment system. In addition, the section introduces challenges related to the resizing. Section 7 summarises the main findings of the study.

2. Measurement methods

2.1 Test surroundings

The case study is an office building in the Helsinki region, Finland. The characteristics of the monitored lift group are shown in Table 1. It is worth mentioning that the monitored lift system is non-regenerative, i.e., the energy recovered during the regenerative operation modes (see Figure 1) is converted into heat in brake resistors. In addition, the loading per car is quite small. In the measured office building, the traffic is light, the lift handling capacity is good and the destination control system (DCS) is used, which all decrease the average car loading. This is not a situation in all office buildings, and the average loading can be higher. The building is further depicted in [7], [13] and [14].

Table 1 Lift group characteristics

Number of units	4
Group control system	Destination control (DCS)
Nominal load, Q	1 500 kg
Nominal speed, v_{nom}	2.5 m/s
Counterweight ratio	50%
Full lifting height	59.1 m
Number of floors	16
ISO 25745-2 usage category	4 (high intensity)

Machinery	Gearless PMSM, Non-regenerative

PMSM: permanent magnet synchronous machine

Traffic statistics, mainly the origin and destination floors, time stamp, and loading percentage, were obtained from the lift monitoring system (LMS). The energy and power consumptions were measured with a Fluke 1760 three-phase power quality recorder installed after the main fuses of the lift in accordance with the ISO 25745-1 standard [15].

2.2 Collected energy data

Traffic data was recorded for one month during March 2014 for all four lifts in the group. Concurrent energy and power data were collected for two days from one of the lifts. The instantaneous power profile, peak power, and travel specific energy consumption were derived from this data set for each start of the lift during the two days. Figure 3 shows example results for lift starts with a distance of 9 floors downwards and, consequently, upwards.

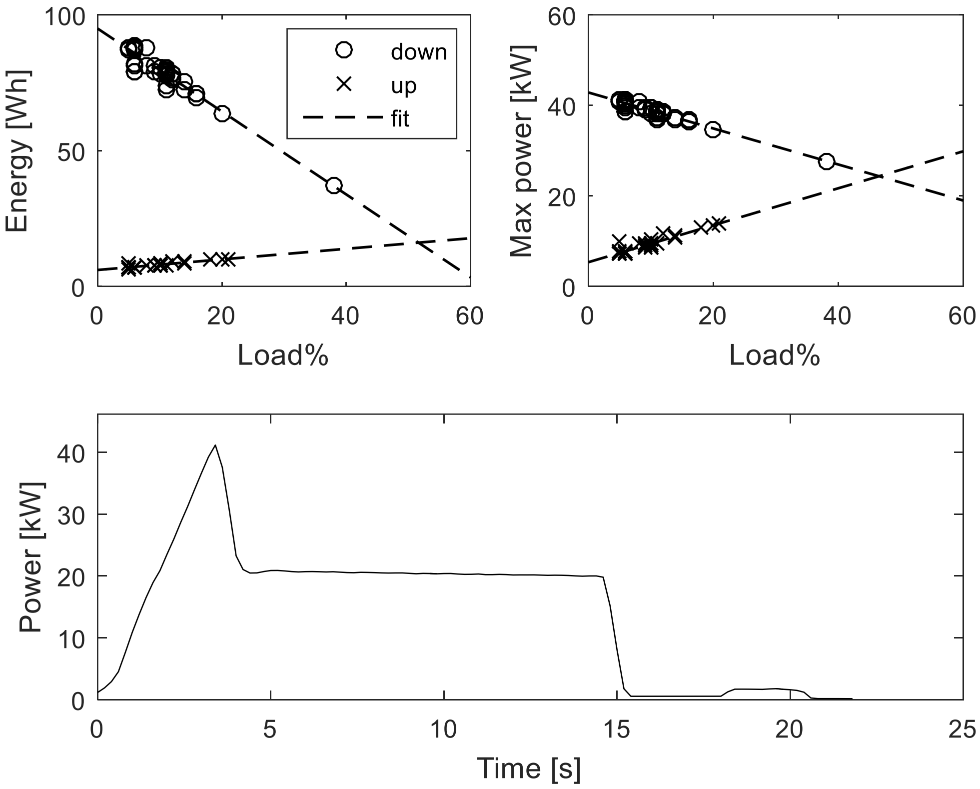

Figure 3 Measured energy and power consumptions for up and down starts over a distance of nine floors, and a power profile of instantaneous power (200 ms) during a start

Clearly, in the measured data, the energy and power depend linearly on the carried mass (load) and the counterbalancing is close to the expected 50% of the nominal load. Presumably, however, the motor efficiency reduction with lower net loads could result in a relatively higher consumption close to the equilibrium of the weights. According to the figure, the effect (steepness in the plot) on energy consumption in the up direction is less than in the down direction and the nominal level of consumption is minor in contrast to the majority of downward starts. In upward starts, the heavier load only decreases the net mass that the drive has to slow down, i.e., the amount of energy converted into heat in the brake resistors decreases.

In a regenerative lift system, the results, especially related to upward starts, would change [7], [10], [11]. The amount of electrical energy to be recovered varies greatly depending on the used technology and direction, distance and concurrent loading of a start. In a favourable situation, a start can also be a net producer of energy. In general, regenerative drives save around 20 – 40% in total electricity consumption compared to traditional lift systems with brake resistors [16]. At this stage of the research, only preliminary estimates can be presented for regenerative lifts (see Section 4.2).

3. Modelling method

The process above provides an empirical model with equations for the energy consumption in relation to the load percentage. The R squared values vary between 0.97 and 0.52. The equations are applied when analysing the impact of counterweight resizing in Sections 4 and 5. Evidently, the downward starts consume significantly more energy than upward starts in the existing lift setup. However, in theory, when the loaded car is heavier than the counterweight, the equations shift. Thus, the calculation model is based on a set of equations, resembling the idea depicted in Figure 4, where the load% difference is

$$\Delta_{\text{load\%}} = \frac{\underbrace{(m_{\text{car}} + K*m_{\text{nominal}})}_{\text{counterweight}} - \underbrace{(m_{\text{car}} + m_{\text{load}})}_{\text{loaded car}}}{m_{\text{nominal}}} = counter\% - load\%, \tag{1}$$

where m_{car} is the mass of an empty car, m_{load} is the mass of the cargo (passengers) and m_{nominal} is the rated nominal load for the lift.

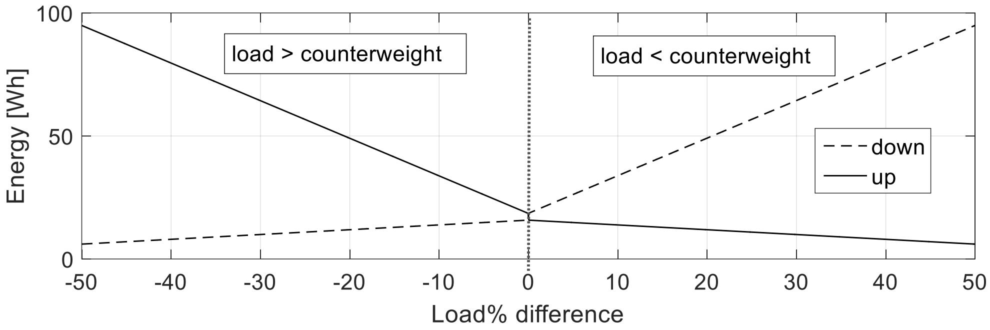

Figure 4 Example of the employed equations for energy for a travel distance of nine floors

Applying the obtained equations enabled determination of the energy consumption of one kilogram of difference in the loaded lift car and counterweight. Combining the equations with the data of each recorded start by the LMS, it was possible to calculate the average daily energy consumption with different counterweight sizes. This method is different from [9] and [10], where the measurements were conducted with actual changes in the counterweight size for a set of weights acting as a load. Nonetheless, the resulting curves appear similar, and the method adopted in this current paper enables the analysis of low counterweight ratios without extensive changes and related safety checks to the lift system, which are further discussed in Section 6.2. On the other hand, in [7], the savings provided by the counterweight adjustment were calculated with simple potential energy equations and employing the LMS traffic data. However, estimating the system inefficiencies is challenging in that approach.

4. Modelled running energy consumption

The following results focus on energy consumption during a weekday since the amount of starts during the weekend is negligible in office buildings [7], [17].

In the test building, during a typical day, the downward starts have, on average, higher loading prior to lunchtime. Similarly, after the lunch, the loading increases for upward starts (see Figure 5). A corresponding profile can also be concluded from [13], where the batch sizes during the lunch period are reported to be considerably higher than during the morning or evening. Compared to individually arriving passengers, the overall number of starts during a day decreases due to the batch effect [18].

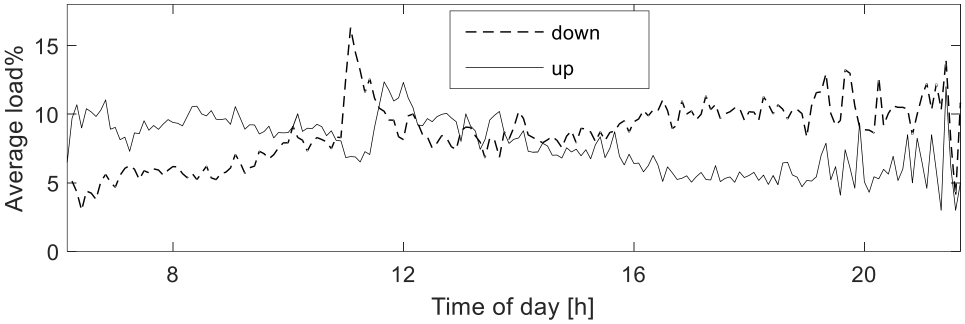

Figure 5 Five-minute averages of start loads during weekdays in March 2014

4.1 Impact of counterweight mass

Resizing the counterweight potentially saves a considerable amount of energy. The overall savings in running energy against the existing 50%-counterbalanced system are substantial, around 50%, even with a fixed counterweight that is sized to match the average load (see Figure 6). With the 30% threshold value for the lowest counterweight ratio employed in [9] and [10] (and introduced in the ISO 25745-2 standard), the modelled savings would be approximately 25%. Thus, this setup could achieve around half of the potential energy savings in contrast to a setup with the counterweight dimensioned according to the average load (8.2% of nominal load). Interestingly, the daily savings show relatively linear dependence on the counterweight ratio between the optimal point and the 50% ratio, at least in the case building and with fixed counterweight sizes. This phenomenon can also be seen in [7]. It should be noted, however, that sizing the counterweight based on the average load may be unwise in systems with a wide loading spectrum because many starts occur with loads far from the average, which increase the energy consumption [7].

Analysing the daily running energy consumption in the monitored building reveals that the achievable savings with the continuously adjusting system are limited to 9%, compared to the fixed but resized counterweight option. Moreover, the perfect equilibrium for each start is difficult to achieve in practice, and frequent changing of the counterweight results in excess starts for the lift just to change the number of weights in the counterweight. For instance, within 11 hours of operation, considering a 15-minute changing interval and an average cycle consumption of 40 Wh, the additional losses would total more than 1.7 kWh per lift, which actually exceeds the saving potential of the continuously adjustable system by more than 100% in the lift under investigation.

Due to the above, none of the continuously adapting systems would ever fully reach the maximum saving potential if the counterweight mass is adjusted with a set of weights at a fixed shaft position. Some improvement can be achieved by increasing the number of weight-adjusting positions based on the traffic profile. However, the floors with heavy traffic are usually restricted to only a few floors, such as entrance and transfer floors, restaurant floors and floors with meeting rooms, which decreases the attractiveness of this idea. Supposedly, one efficient practice would be to change the weight stack only when the lift in any case travels to the suitable floor. Other approaches include patented systems [19] and [20] that claim improved run-time balancing having a gear system that allows changing the effective counterweight mass depending on the momentary loading of the car. However, the added gears increase complexity and, presumably, maintenance needs. Nevertheless, a system with a fixed counterweight with the weight of the car and an additional on-the-fly adjustable counterweight definitely has potential.

In Figure 6, the last column on the right refers to a system where only the energy used to lift the passenger mass is consumed in addition to auxiliary system consumption, such as car lighting, thus, excluding all inefficiencies in the hoisting system. Definitely, further savings in the system could be attained by increasing the efficiency of individual components, such as the drive and motor and reducing the friction in the car and counterweight guide rails. Nevertheless, employing a resized counterweight based on the average load is plausibly a less demanding task than improving the efficiency of mass-produced components that have long and costly design processes. The comprehensive study of lift and escalator efficiency [10] also concludes that optimising the counterweight size is the most cost-effective and fastest method to improve energy efficiency in existing lift installations.

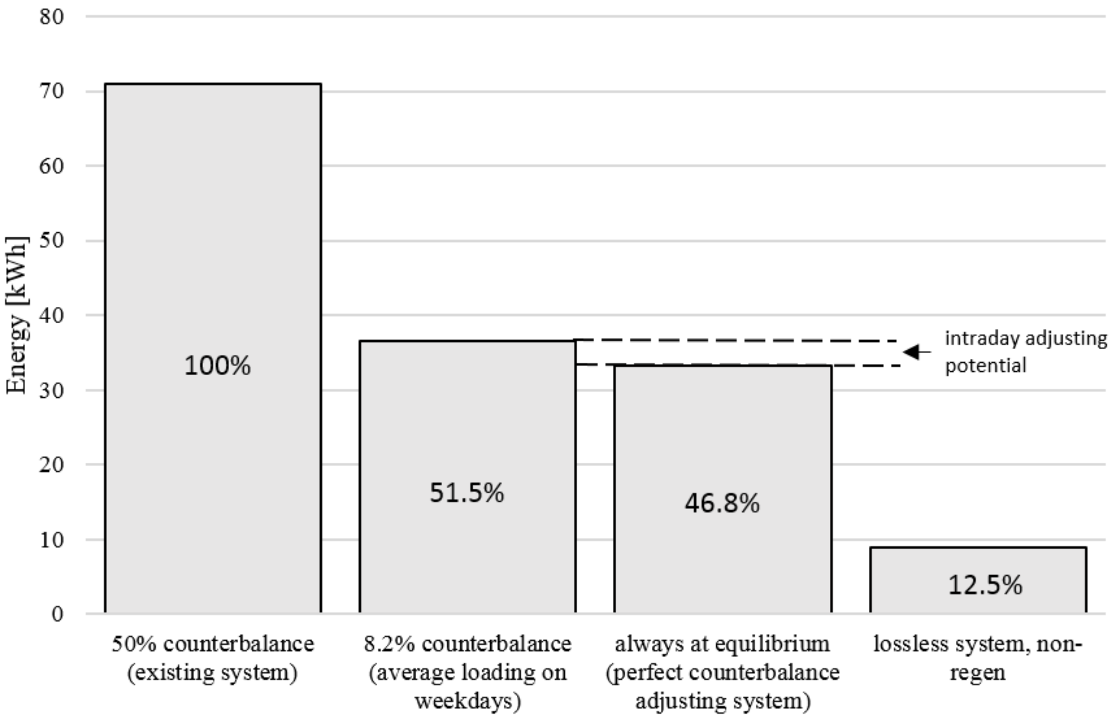

Figure 6 Modelled daily running energy consumption of the lift group on a weekday with different counterweight settings

The attainable additional savings with the continuously adjustable counterweight were minor in the current loading profile due to the small, short-term changes in the loading of the lift during the day (see Figure 5). Most likely, the continuous resizing would be an unattractive feature in the case building. Thus, the paper excludes a more detailed analysis of the performance of different adaptive control schemes. Nevertheless, in a building with clear traffic peaks, a continuously adjusting system may be viable. However, this requires clear differences in the average load between the periods during a day while having little fluctuation within the period. In an adaptive counterweight system, the counterweight mass would change automatically based on the expected loading and travel characteristics of the next time period, in an effort to minimise the energy consumption. This has also been discussed in [9].

4.2 Estimating the effect of regeneration

The previous section presented the results of the observed lift group that was not equipped with a regenerative drive. Even though the focus in this stage of the research is not yet on regenerative lift systems, a preliminary estimate of its impact on the adjustable counterweighing is presented in this section. In the future, regenerative lifts in real traffic conditions should be measured to verify the results presented here.

The preliminary estimates are calculated in the following methodology. The angular coefficient of the equation for the downward travelling lift (lightly loaded = motoring mode) was applied as a base value for the rest. If the lift was considered to operate in a regenerative state (see Figure 1), the coefficient was multiplied by a value of 0.7, representing the reverse efficiency of the whole hoisting system in contrast to the measured value (thus the system efficiency was actually around $\sqrt{0.7} = 0.84$). The efficiency was derived from the reference cycle measurements of a modern regenerative lift by analysing the instantaneous powers occurring in the upward and downward directions. Similar to the method presented in Section 3 (see Figure 4), the equations shift depending on the net load. Figure 7 depicts the outcome of the methodology.

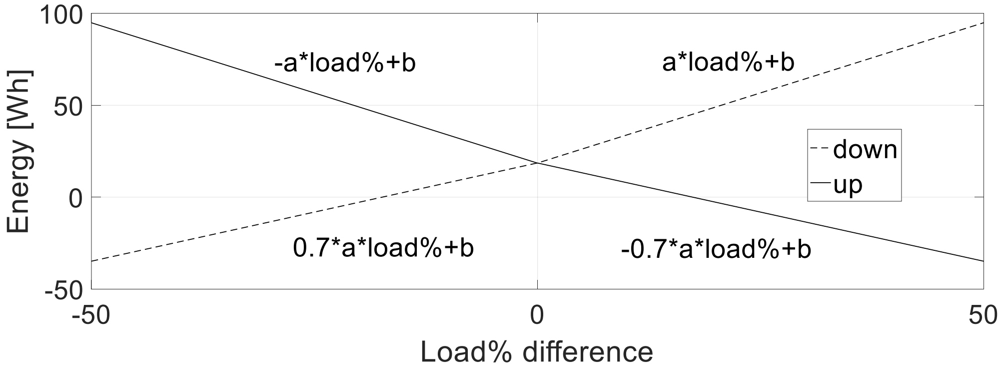

Figure 7 Example of the employed equations for energy for a travel distance of nine floors in a regenerative lift

The new equations estimated for a regenerative drive enabled the calculation of the daily running energy consumption. The modelling was done for fixed counterweights with the existing counterweight ratio of 50%, the 30% ratio discussed earlier and the 8.2% ratio representing the average load.

Figure 8 presents the calculated estimates. The results highly resemble those introduced in the conference publication [7], even though a different calculation methodology was applied from the one applied in the current paper, as mentioned in Section 3. Nonetheless, actual measurements from regenerative lifts in different building types are still required to make any concrete conclusions.

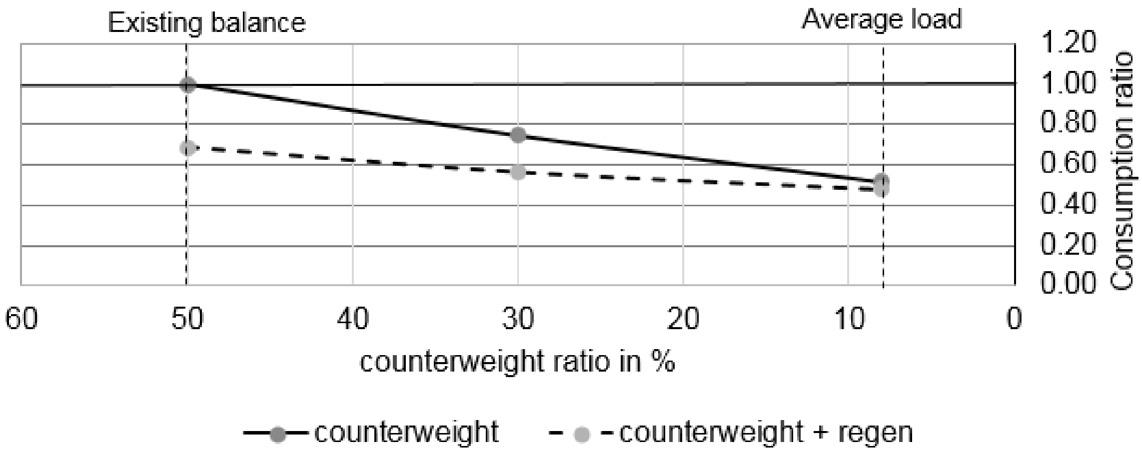

Figure 8 Calculated effects of adjustable counterweighting and regenerative drive on daily running energy consumption

These preliminary results suggest that a regenerative drive is effective in lifts with heavy traffic, but the efficiency gap to a non-regenerative lift diminishes when approaching the optimal counterweight ratio. This is also supported by findings in [7]. Nevertheless, the adjustable counterweighting still benefits lift systems with a regenerative drive. Our model indicates a 30% decrease in running energy consumption in the modelled lift with a counterweight dimensioned to match the average load instead of the common 50% ratio.

Considering the adaptive counterweight resizing during the day, the preliminary model was unable to provide any comprehensive result in the case of a regenerative lift. However, compared to the running energy consumption of the perfect counterbalance adjusting system, presented in Figure 6, the modelled consumption of the regenerative lift was only 2.6% higher with a fixed counterweight ratio of 8.2%. Thus, based on these rough estimates, implementing an adaptive counterweight adjustment system into a regenerative lift does not appear meaningful in the case of a relatively stable loading profile. On the other hand, the benefit in a non-regenerative lift was also considered relatively small but still with three times more potential (see Section 4.1).

5. Energy performance classification

Two commonly known approaches are employed to categorise lifts based on their energy efficiency: the VDI 4707-1 guideline or the ISO 25745-2 standard. The VDI approach is excluded from this study since it cannot be used to analyse the energy consumption of lightly counterbalanced lifts accurately [14]. The VDI 4707-1 applies a load spectrum where 50% of the starts are loaded with at least 25% of the nominal load to estimate the energy consumption of an average start. According to the measurements in this study, however, most of the starts are actually loaded with less than 20%. This paper focuses on the ISO 25745-2 standard since it reflects better the energy performance with different counterweight settings.

5.1 Classification of ISO

The ISO 25745-2 standard categorises lifts into seven classes, A to G, based on the energy efficiency. The energy-efficiency performance level is determined by comparing the measured and calculated values against the threshold values presented in the ISO tables. In addition to the overall energy-efficiency class, the ISO approach includes separate performance levels (1 – 7) for standby and running.

The scope of this article is in the running energy performance level and the overall energy-efficiency class, due to the counterweight resizing affecting only the running energy consumption. The running energy measurements are performed according to the ISO 25745-1 standard. First, a reference cycle measurement is conducted, where the lift is run between the terminal landings with the doors operating normally. This cycle is carried out a minimum of 10 times and the average reference cycle energy consumption is then calculated. Second, additional short-cycle energy consumption measurements are typically performed to increase the accuracy of an annual energy consumption estimate [14].

Next, the effect of the counterweight resizing on the classification process is calculated with the help of the formulated equations and attained traffic data (see Sections 2 and 3), considering a new counterweight size (equilibrium coefficient, *K*) of 8.2% instead of 50%.

5.2 Specific running energy

The ISO approach employs specific running energy values [mWh/(kg*m)] in its calculations. This value refers to the running energy consumption per metre of travel and is calculated as

$$E_{\mathrm{spc}} = \frac{k * E_{\mathrm{rav}}}{Q * 2 * s_{\mathrm{av}}}, \qquad (2)$$

where *k* is the load factor (different from *K*), E_{rav} is the average running cycle energy consumption, *Q* is the nominal load and s_{av} is the one-way travel distance of the average cycle. Contrary to the *J/kg/m* benchmark value introduced in Section 1, the standby energy consumption is excluded.

The load factor *k* is employed to model the impact of the passenger load on the energy consumption due to the measurement cycles being measured with an empty car. The load factor depends on the average load and equations presented in the standard. Unfortunately, the ISO standard has no equation for counterbalanced lifts with an equilibrium coefficient under 30%. Nevertheless, for this calculation example, when the counterweight is equal to the average load, the loading factor can be approximated with a load factor of $k = 1$, as the average travel consumption was calculated by presuming the average load.

The ISO running performance classes start from Class 1 with a threshold value of 0.72 mWh/(kgm), and the next class threshold is always 1.5 times more than the previous, i.e., 1.08 mWh/(kgm) for the running performance Class 2. With Equation (1) and the corresponding energy consumption (see Section 3), the specific running energy values and the resulting running performance class for the monitored lift were as depicted in Table 2. The change in the running performance of the ISO standard seems to correspond well with the savings achieved in the daily running energy consumption, discussed in Section 4.

Table 2 Specific running energies and running performance classes according to Equation (2)

	$E_{\text{spc,old}}$, K=50%	$E_{\text{spc,new}}$, K=8.2%	Change%	Class old→new
ISO	0.977	0.541	-45%	2 → 1

5.3 Specific overall energy

The energy efficiency class is the most critical property of a lift from the market perspective. It relates to both running and standby energy consumptions. In contrast to the running performance class limits, the standby limits double with each step starting from 50 W. For example, Class 2 is up to 100 W and Class 3 up to 200 W. The measured standby power consumption for the lift was 172 W.

The ISO 25745-2 presents limits for daily energy consumption. The energy efficiency Class A is achieved when the daily consumption is less than or equal to specified:

$$E_{\mathrm{d,A}} \leq E_{\mathrm{spc,A}} * Q * n_{\mathrm{d}} * \frac{s_{\mathrm{av}}}{1000} + P_{\mathrm{st,A}} * t_{\mathrm{st}}$$

$$= 0.72\,\frac{\mathrm{mWh}}{\mathrm{kgm}} * 1500\ \mathrm{kg} * 750 * \frac{21.5\ \mathrm{m}}{1000\,\frac{\mathrm{mWh}}{\mathrm{Wh}}} + 50\ \mathrm{W} * 21\ \mathrm{h}$$

$$= 18\,465\ \mathrm{Wh}\,, \qquad (3)$$

where n_{d} is the daily number of starts, which is by default 750 for this building type, $P_{\mathrm{st,A}}$ is the Class 1 standby power limit and t_{st} is the standby time per day. In this example, the daily standby time is adapted from the tables of the VDI 4707-1 guideline for the specific building type.

Table 3 shows the calculated values before and after the counterweight resizing. The calculations presumed the same number of starts and average trip length as Equation

(3). The results are in line with the running performance class changes, as the specific running energies are included in both equations, and the standby consumption is low in comparison with the running energy consumption in this building type.

Table 3 Calculated daily energy consumption before and after the counterweight resizing and its effect on the energy efficiency class

	$E_{d,old}$, K=50%	$E_{d,new}$, K=8.2%	Change%	Class old→new
ISO	27 248	16 702	-39%	B → A

6. Discussion

This study was conducted in a mid-rise office building with a lift group of high handling capacity. Therefore, the results are subject to change, e.g., in buildings with more floors and longer travel distances. The longer travel distances involve larger changes in the potential energy of the carried load (passengers and goods). Consequently, the ratio of energy consumption and generation related to acceleration and deceleration phases is decreased. On the other hand, lift systems with less handling capacity carry more passengers (increased load) with fewer starts. Thus, the savings achieved with the counterweight resizing and the effect of regeneration can be rather different from the ones presented in this paper. Nevertheless, the benefits of counterweight resizing and regenerative systems presumably increase in tall buildings with higher traffic (ISO 25745-2 usage categories 4 – 6).

6.1 Potential improvements and additional benefits

In the case study, the achievable energy savings were minor with the continuously adapting counterweight in contrast to the optimally dimensioned fixed counterweight. Nevertheless, an adaptive counterweight adjustment system may be viable in buildings with heavy traffic peaks.

The counterweight adjusting system can also be enhanced. For instance, in addition to logging the average load, the number of passengers waiting in the lobby could also be monitored. The information on the number of awaiting passengers helps to reduce stops with already too packed cars, which would not fit the incoming new passengers or where the net loading would become unfavourable in terms of energy efficiency. The monitoring could be performed via multiple people counting methods, such as a camera [21] or a laser scanner. A patent in [22] also proposes a call panel input by the caller for the number of awaiting passengers to improve the system flexibility and energy efficiency.

As discussed in [9], the energy savings could be verified by measuring the actual energy consumption, and the control system could apply the energy measurement data instead of the plain load data. This would improve the optimising process of the counterweight size and adjustment schedule. To further support the process, one approach would be to use a lookout table of simulated energy consumptions or an online database of similar lift setups. The online database would also support the lift manufacturers in designing and commissioning more energy-efficient lifts.

Resizing the counterbalance has multiple benefits in addition to reducing the energy consumption of the lift unit. For example, the resistive losses decrease and, in the case of a non-regenerative drive, the brake resistor heat diminishes. This reduces the ventilation and cooling demand and related electricity consumption [7]. Resizing can also help to reduce instantaneous peak power demand. As demonstrated in Figure 3, the maximum power required during a downward start reduces towards the equilibrium of the weights. Thus, when designed carefully, the resizing of the counterbalance can help to decrease the main fuse size of the building (lower distribution costs) and reduce strain on the power grid. Consequently, a poorly implemented counterweight adjustment system exposes the grid to even higher power peaks than before, as discussed in Section 6.2.

6.2 Drawbacks, limitations and challenges

Challenges in counterweight resizing include possible regulatory limitations and changes in the lift hoisting design:

1. The motor and drive nominal powers must be increased when the counterweight mass is reduced from the typical 50%, as the maximum net load of the lift increases [7]. This also means that the peak instantaneous power demand is potentially increased, which may be harmful in weaker grids relying, for example, on local energy production. Another option would be to decrease the lift speed, when necessary, to keep the drive motor within its rating, but this increases travel times and perhaps influences the handling capacity during peak traffic periods [8]. Moreover, an additional speed controller would have to be designed to meet all the safety regulations. The third option would be to adjust the nominal load rating of the lift to better correspond to the actual passenger density [8]. This typically helps to decrease the rated nominal load, which reduces the need to increase the drive motor power. A similar approach has been proposed in [23] for non-commercial vehicle lifts. To guarantee the safety, the approach introduces the concept of a pawl device which would be active during each stop to handle situations when the load exceeds the new, smaller rated load. The upsides from decreasing the rated nominal load include direct benefit from material usage reduction, decrease in related labour costs of installation and, most importantly, the resulting energy savings during the operation life-time (the motor is run nearer to the optimum in terms of efficiency and less energy is consumed in lifting the lighter counterweight) [23].
2. The continuously adjustable counterweight system requires development in the control and mechanical designs to create a reliable, cost-efficient and durable system. Especially, the altered system must comply with the considerations and tests determined in the lift safety standard EN 81-50, sections 5.11 and 5.12. For instance, reducing the counterweight ratio may induce slipping on the traction wheel. Moreover, the lift industry is moving towards lighter materials, reducing the weight of the car, and consequently, further decreasing the total mass of the

counterweight. Nevertheless, methods exist to reduce the slipping [24]. Furthermore, obtaining efficiency improvements in other lift components is likely to be more challenging due to their mature technology.

3. Counterweight resizing is not beneficial in some lift setups. For example, small residential lifts are most likely out of the scope of counterweight resizing, i.e., the typical 50%-counterbalanced lift is reasonably dimensioned because the nominal load is only some hundred kilograms and achievable energy savings are limited. Moreover, the savings with resizing the counterweight are less in regenerative lift systems, which are becoming more popular in the lift market. Nevertheless, the energy consumption can still be decreased considerably, even by as much as 30 – 40%, in these systems (see Section 4.2 and [7]).
4. It is also challenging to determine the energy efficiency class of lifts with resized counterweights. Especially, the load factor value to be employed is uncertain, because it is unspecified for low values of K (counterweight ratio). Thus, it would benefit to measure the actual average daily energy consumption and grade the lift accordingly.

7. Conclusions

Over-dimensioned counterweights are common in existing lifts. Counterweight resizing provides a promising approach to improving the energy efficiency of lifts. However, the lift industry and code and standards provide only a few solutions and little information related to counterbalancing. This paper analysed the resizing of the counterweight based on measured daily lift traffic and loading characteristics. According to the study of an office building, significant energy savings can be achieved with optimal sizing of the counterweight. In the monitored lift setup, up to 50% of the running energy consumption could be conserved compared to the situation with the existing over-dimensioned counterweight. This considerable saving was calculated presuming a fixed counterweight which is dimensioned to match the average load. However, adjusting the counterweight mass during a day was considered undesirable, due to the limited additional savings in contrast to the expected increase in the complexity of the mechanical and control systems to enable the adaptive counterweight.

Sizing the counterweight to an untypically low weight also affects the energy efficiency class of the lift. The existing classification approaches offer limited support for this type of lift systems. The results, nevertheless, indicate that the ISO 25745-2 running performance and the overall energy efficiency class tend to improve.

In the near future, a similar counterweight analysis on a regenerative lift will be performed. Furthermore, the research is expanding to more buildings and other building types to analyse the potential of adaptive counterweighing in general. In addition, discussions on practical issues and improvements should be conducted with experts and engineers in the field to guarantee safety and to secure high performance both in ride experience and energy efficiency.

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Figure captions

1. A simplified illustration of a counterbalanced traction lift system and operation modes during starts, adapted from [11]
2. Simplified example of a current-load curve for determining the equilibrium coefficient
3. Measured energy and power consumptions for up and down starts over a distance of nine floors, and a power profile of instantaneous power (200 ms) during a start
4. Example of the employed equations for energy for a travel distance of nine floors
5. Five-minute averages of start loads during weekdays in March 2014
6. Modelled daily running energy consumption of the lift group on a weekday with different counterweight settings
7. Example of the employed equations for energy for a travel distance of nine floors in a regenerative lift
8. Calculated effects of adjustable counterweighting and regenerative drive on daily running energy consumption