Energy consumption and efficiency potentials of lifts

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Abstract

Lifts can account for a significant proportion of energy consumption in buildings. In a research project that was concluded in 2005, the energy consumption of 33 lifts from a variety of manufacturers was measured. The most important finding concerned the surprisingly high stand-by consumption, which accounted for between 25 and 80 percent of the total consumption. Average efficiency rates were favourably high at around 60 percent. One notable finding was that modern hydraulic lifts can be just as efficient as traction lifts thanks to the use of counterweights or energy storage. Overall efficiency shall be achieved by reducing stand-by consumption and using energy-efficiency concepts and criteria for architects, designers, planners and customers.

Current situation, objectives

The electricity consumption of lifts is dealt with in the new SIA standard 380/4 ("Electricity in buildings") [1], and is also an integral part of the declaration of overall energy consumption by building systems (energy certificate for buildings). A research project that was concluded at the end of 2005 [2] set out to extend the somewhat limited knowledge about the electricity consumption of lifts by carrying out measurements. The broad-based project team was supported by the lift industry in that Schindler Aufzüge AG provided technical assistance while seven other manufacturers provided the necessary local support for the measurements.

Project partners

- Swiss Agency for Energy Efficiency (S.A.F.E.), project management
- Swiss Federal Office of Energy, SwissEnergy programme
- Swiss Society of Engineers and Architects (SIA)
- City of Zurich civil engineering office, and energy-efficiency fund of the City of Zurich electricity works (ewz)
- Office for Environmental Protection and Energy (AUE), Basel-Stadt
- Schindler Aufzüge AG
- Other companies affiliated to the Association of Swiss Lift Manufacturers (VSA)
- S.A.L.T. (Swiss Alpine Laboratories for Testing of Energy Efficiency], Chur), implementation of measurements

The main objectives of the project were to determine the level and structure of electricity consumption by lifts in Switzerland and to identify efficiency measures and ways of implementing them in various situations. For measurement purposes, typical lift systems in use in Switzerland were classified by type, size, building type and lift properties (Table 1, Figure 1).

Table 1 No. of measured lifts by year of manufacture and building category

Year of manufacture	Prior to 1980	1980 - 1997	After 1998	total
Residential buildings	1	1	12	14
Hospitals/clinics	-	2	1	3
Shops	-	-	1	1
Office blocks	1	2	5	8
Car parks	1	-	3	4
Industrial buildings	-	1	2	3

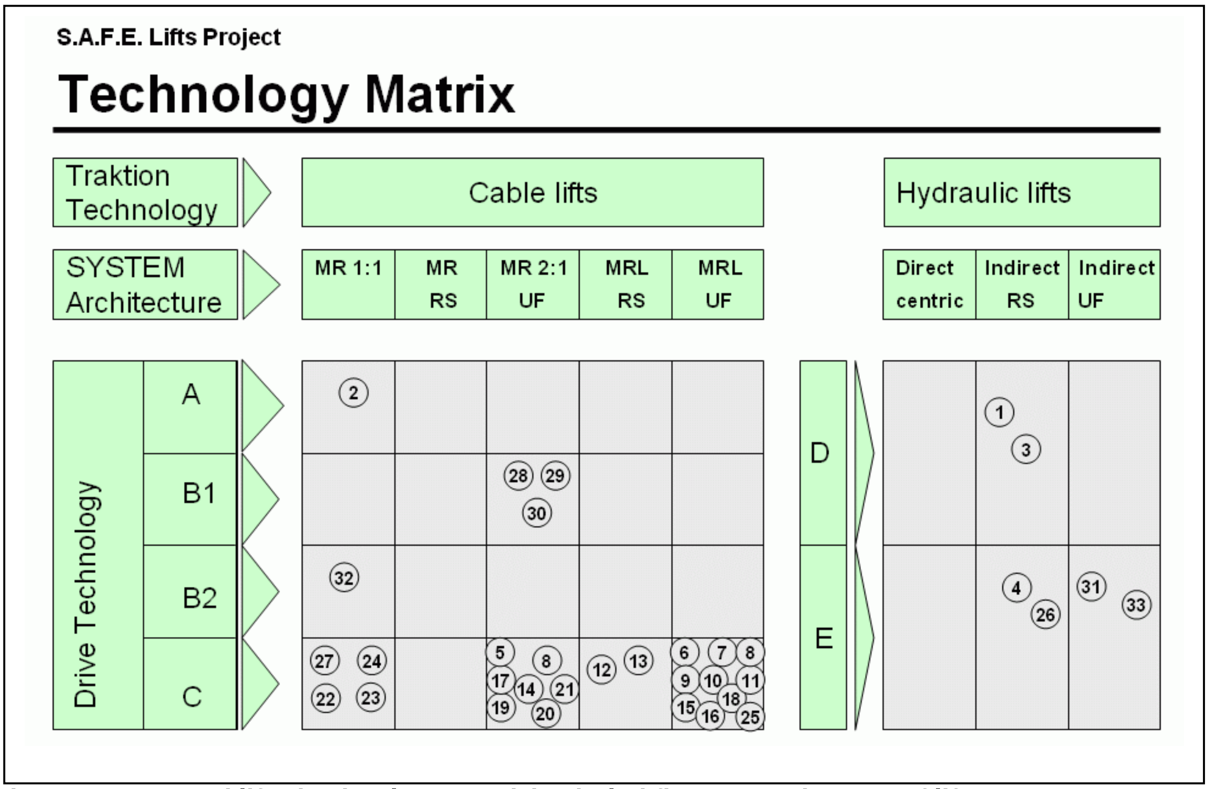

Fig. 1 Measured lifts (technology matrix). Circled figure = project no. of lifts

Key to technology matrix:

Traction lifts:

A		Worm gearing with AC motor for fine adjustment (2 speeds)
B1		Gearing with AC motor, voltage control
B2		Gearing motor, with frequency converter
C		Gearless drive, permanent-magnet motor with frequency converter
MR 1:1	=	Lift with machine room, cabin suspension 1:1 (direct, centrical)
MR / RS	=	Lift with machine room, direct eccentrical suspension (“backpack”)
MR 2:1 / UF	=	Lift with machine room, suspension via rollers beneath cabin / 2:1 indirect suspension (lower block)
MRL / RS	=	Lift without machine room, with eccentrical suspension
MRL / UF	=	Lift without machine room, suspension via rollers beneath cabin

Hydraulic lifts:

D/E		Hydraulic valve control
Direct centrical	=	Central hydraulic hoist beneath cabin
Indirect RS	=	Hydraulic hoist beside cabin, suspension indirect via roller on hoist
Indirect UF	=	Hydraulic hoist beside cabin suspension, indirect via roller on hoist, suspension 2:1 via rollers beneath cabin

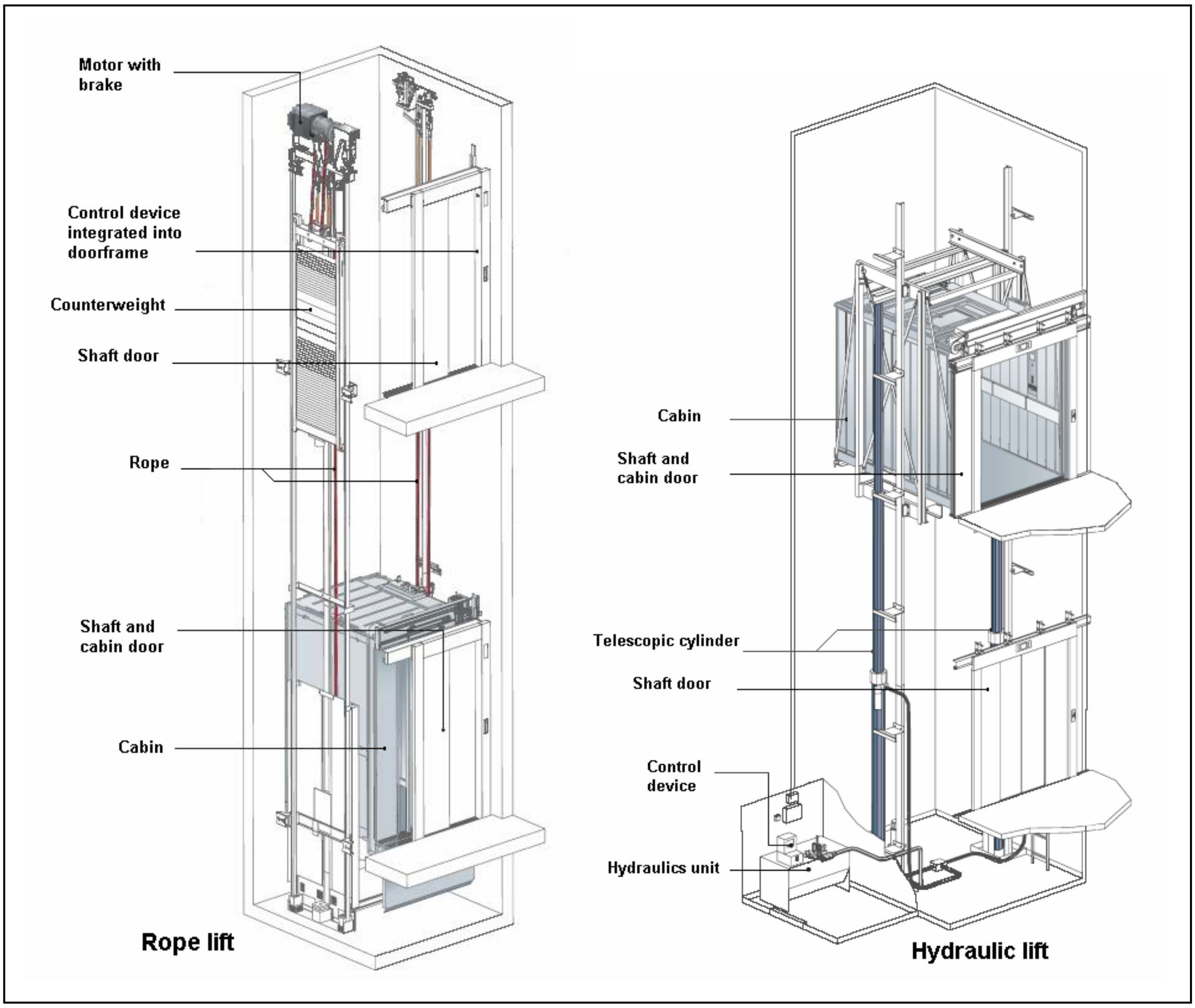

Fig. 2 Diagram showing construction of modern lifts

Source: Schindler Aufzüge AG

Measurements

To measure the energy consumption while in operation, each lift was put through a single travel cycle (ascent and descent) while empty, and its stand-by consumption was measured. In this way the minimum and maximum loads were recorded. Due to the extremely wide range of loads, the demands placed on the measuring equipment were very high: it was necessary to work with mobile recording devices that were easy to install, covered a range from a few watts in stand-by mode up to 30 kW three-phase, including negative feed for recuperation, and guaranteed a high degree of accuracy. On top of this, the relevant safety requirements also had to be met. The readings per travel cycle were recorded three times per second in order to ensure that peak levels due to acceleration were included in the measurements.

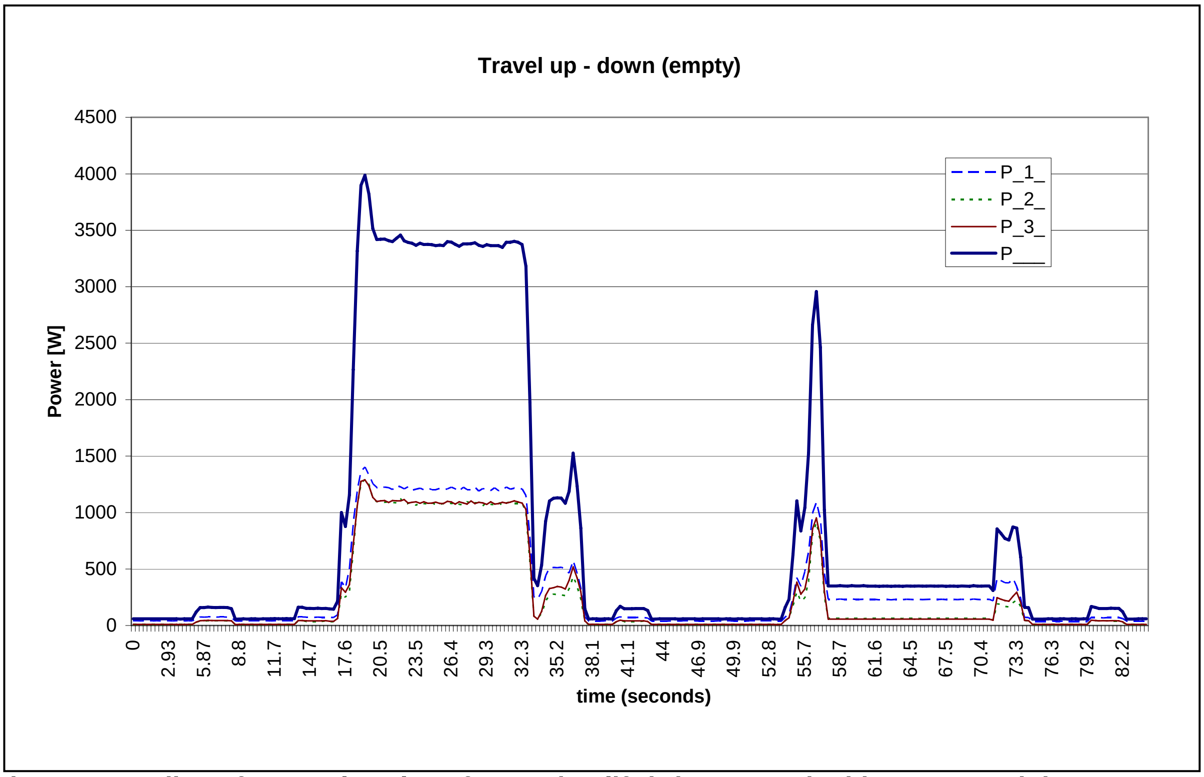

Fig. 3 Readings for travel cycles of a traction lift (when empty) with counterweight. P (strong) = total load, P_1/2/3 (thin/dotted) = 3 phases.

The graph in Fig. 3 depicts the typical readings for travel cycles of a traction lift (when empty) with counterweight. The segments before and after the almost constant hoist segments show highs and lows (due to acceleration and braking), and minor loads due to door operation are also visible.

In order to determine the energy consumption for standard usage (representing typical use) from the highs and lows recorded during ascents and descents over the full hoist height, the calculation method defined for SIA standard 380/4 [1] was applied. This method describes load factors and the proportion of corresponding travel cycles by drive technology, as well as a hoist height factor, so that the energy required for moving the lift can be calculated using the maximum hoist height, motor output and travel speed, as well as the number of travel cycles; stand-by consumption can be calculated on the basis of the corresponding power consumption and 8,760 hours of operation.

Stand-by and travel-cycle energy consumption

The number of travel cycles is the decisive factor for determining the energy consumption of a lift in motion. For all lifts in the study (with the exception of 5 brand-new ones), this figure was obtained by evaluating the travel cycle meter, and was used for calculating the energy consumption (Fig. 4). The figures thus obtained were used in the calculation for standard usage by type of building in accordance with SIA standard 380/4: 60,000 for residential buildings, 200,000 for office buildings. The results can vary enormously, even for the same types of buildings.

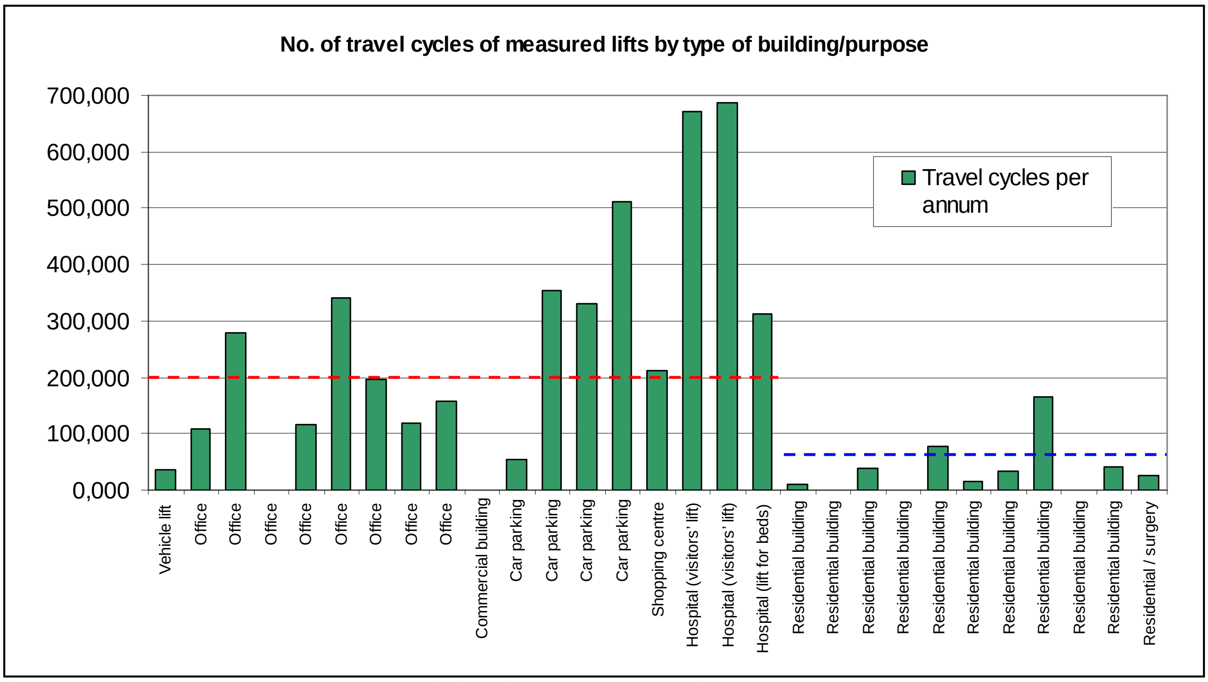

Fig. 4 Travel cycles of measured lifts by type of building

To compare stand-by and travel-cycle consumption (Figs. 5 and 6), the annual travel-cycle energy consumption ($E_{F,a}$) was calculated as follows, in accordance with the method defined in SIA standard 380/4:

$$E_{F,a} = \frac{Z_F * k1 * k2 * h_{\max} * P_m}{v * 3600}$$

$E_{F,a}$ Energy requirements for moving cabin (travel cycles) in kWh per annum

Z_F Number of travel cycles per annum

k1 Average load factor (technology factor):
rope traction 0.35 (with recuperation 0.21), hydraulic w/o counterweight 0.3

k2 Hoist height factor, average/maximum hoist height = 1 if 2-storey, otherwise 0.5

h_{max} Maximum hoist height, between lowest and highest stop, in metres

P_m Motor output (as a rule, nominal output as per rating plate), in kilowatts

v Speed in metres per second.
Formula “1/(speed * 3600)” indicates the travel time in hours (simplified!)

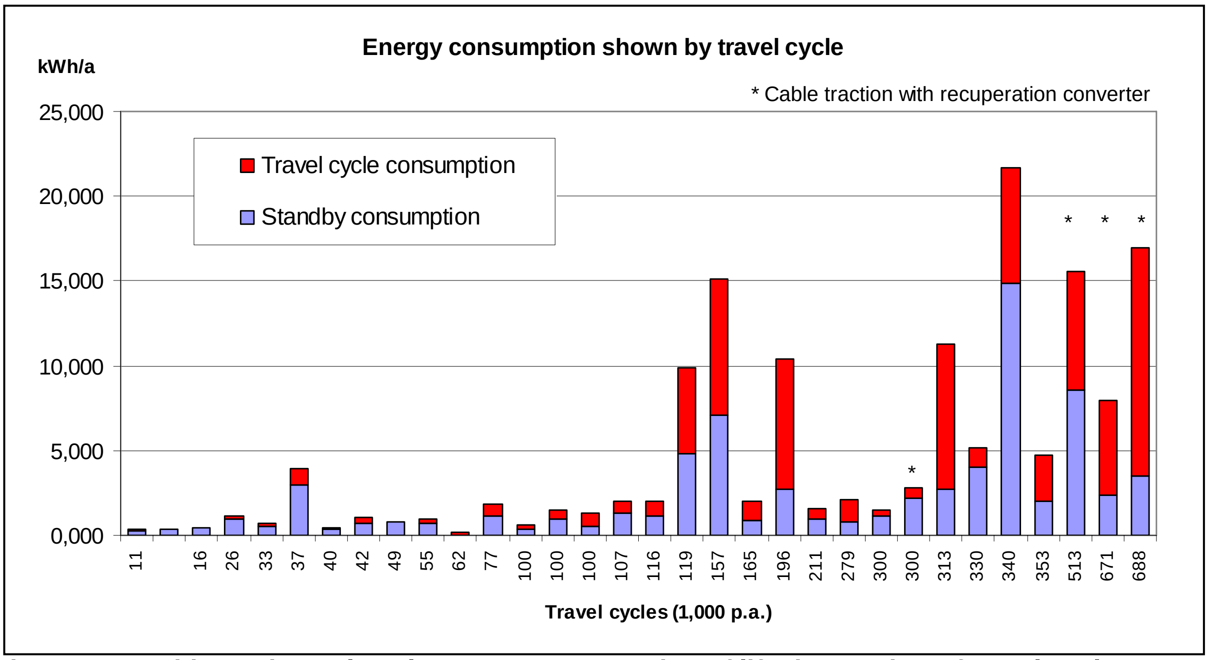

Fig. 5 **Stand-by and travel-cycle energy consumption of lifts by number of travel cycles; travel-cycle consumption calculated using the above formula.**
Lower travel-cycle consumption despite a higher number of travel cycles may be attributable to nominal load, motor output and hoist height. No basic conclusions can be made.

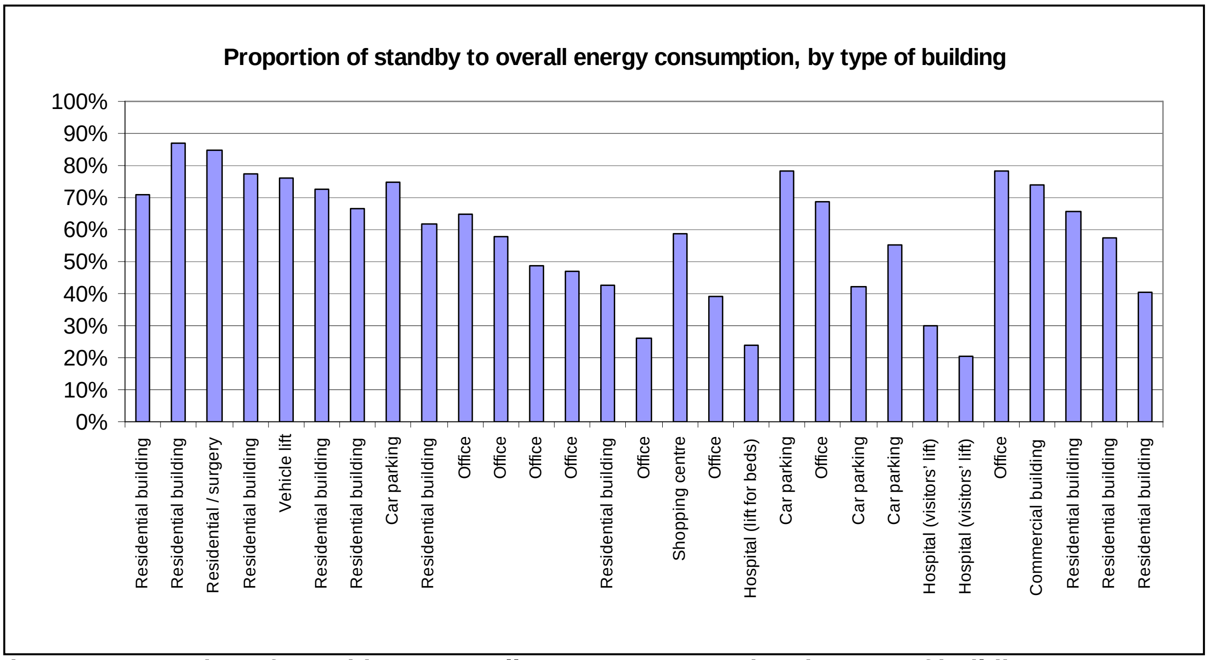

Fig. 6 **Proportion of stand-by to overall energy consumption, by type of building, sequence as in fig. 5, except 3 lifts where not applicable.**
Figures below 30% indicate systems with very high numbers of travel cycles.

Efficiency of lift drives

By using the method for calculating drive energy consumption per travel cycle as defined in SIA 380/4 [1, 3] it was possible to measure the efficiency of the drives of the lifts included in the study on the basis of fundamental physical data (hoist height, cabin weight, speed). For this purpose, the “load cycle” data with maximum motor output were used. In the case of traction lifts, this concerns the descent when empty (due to the counterweight); in the case of hydraulic lifts without counterweight or air accumulator, this concerns the ascent with nominal load. The figures thus obtained indicate an uncertainty factor, since the exact cabin weights were not known. The calculated average degree of efficiency was 60 percent, which was in line with expectations. The efficiency rates for hydraulic lifts with counterweight were similar to those for traction lifts. Measurements concerning lifts with recuperation (which require significantly higher investments) were of particular interest. Degree of recuperation refers to the ratio of recuperated energy during ascent divided by the required energy during ascent and descent. For the 5 lifts with recuperation, the readings varied from a disappointing 9 percent up to a satisfactory 47 percent. Here too, careful optimisation appears to be essential in order to utilise the technical potential.

Projection and composition of consumption

The analysis of the electricity consumption per travel cycle and year for typical traction lifts resulting from the measurement campaign (Table 2) allows for a comparison of energy requirements. But as the measurements indicated, significant variations may occur in some systems for a variety of reasons.

Table 2 Energy consumption of typical traction lifts (type C as per Fig. 1)

Type of building/purpose	Capacity	Speed	No. of stops	Wh per cycle	No. of travel cycles p.a.	kWh p.a., including stand-by	% in stand-by mode
Small apartment building:	630 kg	1 m/s	6	4	40,000	950	83%
Office block/medium-sized apartment block:	1,000 kg	1.5 m/s	8	13	200,000	4,350	40%
Hospital, large office block:	2,000 kg	2 m/s	12	19	700,000	17,700	25%

The projection in Table 3 shows that 58 percent of the energy consumption of lifts is attributable to stand-by mode. This figure would be even higher if similar systems that are not covered by the Lifts Ordinance (e.g. inclined haulage, stairlifts – which have relatively low utilisation frequencies) were included in the projection.

Table 3 Projection of energy consumption of lifts in Switzerland (type of building/purpose shares estimated). The total of 280 GWh p.a. is equivalent to 0.5 percent of the country's electricity consumption.

Type of building/purpose	No. of lifts	%	Typical lift						Projection as per SIA 380/4					
			Storeys	Hoist height	Travel cycles p.a.	Speed	Capacity		Energy			% of total energy		
							Motor	Stand-by	Stand-by	In motion	Total	Stand-by	In motion	Total
				m		m/s	kW	W	GWh	GWh	GWh			
Residential dwellings	97,500	65	6	14	40,000	1	6	90	77	16	93	28	6	34
Hospitals	1,500	1	12	30.8	700,000	2	25	500	7	19	26	2	7	9
Clinics	13,500	9	8	19.6	300,000	1.6	10	200	24	24	48	8	9	17
Shops	6,000	4	3	5.6	200,000	1.6	20	150	8	4	12	3	1	4
Offices	18,000	12	8	19.6	200,000	1.5	21	200	31	48	79	11	17	28
Car parks	6,000	4	4	8.4	60,000	1.6	18	100	5	2	7	2	1	3
Industrial buildings (goods lifts)	7,500	5	4	8.4	40,000	0.8	30	150	10	4	14	4	1	5
Total	150,000	100							162	117	279	58	42	100

Measures to reduce stand-by consumption

Stand-by consumption incorporates a broad variety of components. From the point of view of energy efficiency there are two major factors that can cause unnecessarily high stand-by consumption: permanently running cabin lights and door locking devices, which require constant power. With the present-day status of technology, the stand-by consumption of a lift in an apartment block ranges from 40 to around 100 watts, but in view of the negative factors referred to above, this figure may also be considerably higher.

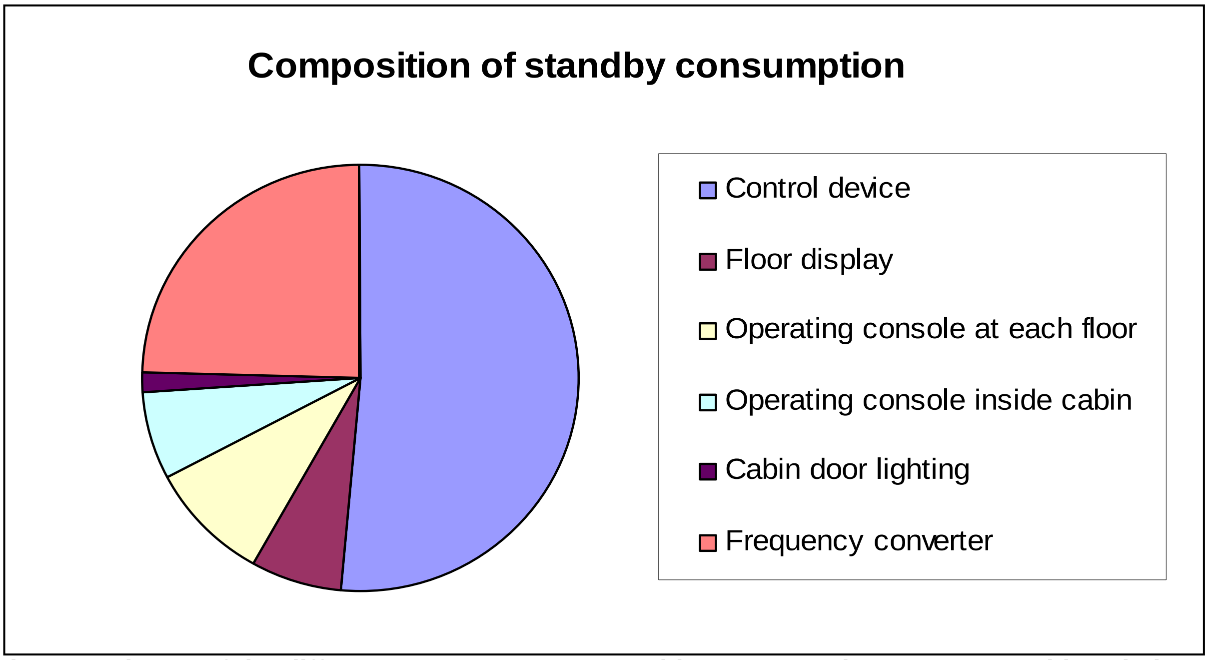

Fig. 7 Shares of the different components to stand-by consumption – example with switch-off of cabin lighting facility.

Source: U. Lindegger

Potential ways in which stand-by consumption can be reduced include:

- Switching off the frequency converter control device and other control functions when the lift is not in motion. During off-peak periods, a stand-by mode requiring a lower power supply would be feasible, e.g. similar to the sleep mode used in electronic devices, would be feasible. Under certain circumstances this would lead to slightly longer waiting (wake-up) times.
- Use of more efficient power supply units (switched units, toroidal transformers)
- Use of efficient display options (e.g. LEDs)

Despite the use of automatic switching devices, lighting in lifts still contributes to overall energy consumption to a substantial degree if inefficient solutions such as halogen filament lamps are used. In this context, lift suppliers could take efficiency into account as a criterion in addition to design.

Developments in the area of drive technology

Hydraulics versus rope traction

Our measurements and studies have shown that hydraulic lifts, which up to now have been generally regarded as inefficient compared to traction lifts, are no less efficient if the newest technologies are used. Any progress is slow here because the investment costs are slightly higher, but the advantages to be gained thanks to lower requirements concerning motor capacity on the other side can help in reduceing costs. A variety of advanced technologies are available on the market or are currently under investigation:

- Closed instead of open loop control of valves
- Counterweight (possible with “hydraulic indirect”)
- Energy storage (instead of counterweight)

Recuperation converters

A perfect lift drive would feed exactly the same amount of energy back into the grid during ascent as it requires for its descent (min./max. load travel cycle). In this case, the ratio of recuperated energy to required energy would be 1:1. However, real lifts also require energy for accelerating, braking, stopping, overcoming friction and for motor losses, and if at all this energy can hardly be recuperated. Thus the degree of recuperation (ratio between recuperated energy fed back during minimum load travel divided by the energy required during complete ascent and descent cycle) is unlikely to exceed 50 percent, and in the case of smaller lifts the limit is closer to 30 percent (see “Efficiency of lift drives” section). In terms of both energy efficiency and economic viability it therefore primarily makes sense to use recuperation converters in large lifts with a high degree of utilisation.

Optimisation of counterweight

According to data provided by the lift industry, the average occupancy rate of lifts is only 20 percent of the nominal load, whereas the figure for counterweights is 40 to 50 percent. Optimisation in terms of smaller loads would result in a more favourable balance with corresponding savings in energy required for travel cycles.

New technologies

<u>Matrix converters</u> do not have an intermediate DC circuit and thus have the potential for reducing losses. However, there are still a few technical problems associated with their use in lifts, and in the next few years we will find out whether it will be possible to develop a suitable solution. <u>Linear motors</u> would in fact be suitable as lift drives in view of the advantage of fewer moving parts and more precise positioning, but a number of obstacles still have to be overcome, including strong lateral force (friction!) and the technical complexity associated with the greater length of such motors.

Energy-conscious planning and dimensioning

Lift systems are going to be installed in buildings to an increasing extent, including in those with a low number of storeys. As more and more lifts are put into use, additional attention should be paid to their energy efficiency. In order to find suitable solutions from the point of view of economic viability and energy efficiency, it is important to incorporate the following aspects during the planning stage:

For planning purposes, the required <u>transport capacity</u> should be specified on the basis of the following criteria:

- Type of building (residential, office, etc.)
- Occupancy of building (no. of people per floor)
- Location of lifts (thoroughfares, location of rooms, storage areas, etc.)
- Utilisation patterns

The <u>number and size</u> of lifts should be determined on the basis of anticipated demand for transport capacity. The following general rules apply with respect to the specified cabin size:

- In residential buildings with maximum 5 storeys, normally 1 lift is required with a capacity of 630 kilograms and interior cabin dimensions of 1.1 x 1.4 metres (in order to accommodate wheelchairs).
- In apartment blocks with more than 7 storeys, at least 1 lift is required with a capacity of 1,000 kilograms and cabin dimensions of 1.1 x 2.1 metres (to allow for transport of furniture, stretchers, etc.). For higher capacities it is important to consider whether to install a bigger and faster lift or a second one.
- For all other buildings, detailed analyses of transport demand and patterns have to be carried out.

Accelerating and braking cause a substantial share of the travel-cycle energy consumption, increasing with lift speed (cf. "Recuperation converters" above). The choice of lift speed should therefore be made on the basis of the following rules while taking energy consumption and travel time into account:

Travel time for entire hoist height:

- For residential buildings — 25 to 35 seconds
- For office blocks, hotels and hospitals — 20 to 32 seconds

These criteria result in the following typical theoretical speeds:

- Residential building, 4 storeys, hoist height 9 metres — 0.26 to 0.36 metres per second
- Office block, 10 storeys, hoist height 27 metres — 0.84 to 1.35 metres per second

Since time for acceleration and braking also has to be taken into account, slightly higher speeds are required in practice. Thus for residential buildings with up to 6 storeys, the standard minimum speed of 0.63 metres per second is sufficient. With respect to transport capacity, the possibility should be considered that, under certain circumstances, choosing a slightly faster lift could eliminate the need for a second one. In office blocks, speeds of over 1 metre per second are only truly required in buildings with more than 8 storeys.

Choice of an energy-efficient lift system

The following construction properties have an influence on the energy efficiency of lifts:

- System architecture: Suspension (centrical, eccentrical, etc.). Centrical suspension and low-friction guide elements reduce (friction) losses.
- Drive: Adjustable speed motors accelerate with lower losses than is the case with pole changing motors that have been widely used in the past. By comparison with conventional worm gear mechanisms, drive losses can be reduced by using gearless or planet gear drives. A travel cycle with slower acceleration is more efficient but takes slightly longer.
- Control mechanism: Control mechanisms with collective operation save travel energy versus taxi operation (i.e. without stops in between). Adjustments can be made according to time of day. And of course, attention has to be paid to stand-by consumption!

Conclusions

There are high saving potentials in lift systems. Two major paths lead to higher overall efficiency: Lowering stand-by consumption, that should be addressed by the lift industry and demanded by the buyers' side . On the other hand, in an integral planning process of architect, planner, orderer and lift supplier the system should be optimized regarding design and technology to satisfy comfort, cost and energy requirements.

References

[1] *Electricity in buildings* (2006), SIA standard 380/4, Swiss Society of Engineers and Architects (SIA), Zurich

[2] Nipkow, J., *Elektrizitätsverbrauch und Einspar-Potenziale bei Aufzügen*, Forschungsprojekt-Schlussbericht, Bundesamt für Energie 2005. Download from: www.electricity-research.ch / *Electricity consumption and efficiency potentials of lifts*. Research project, final report. Swiss Federal Office of Energy, 2005

[3] M. Lenzlinger, Report on SIA standard 380/4: *Energetische Vorgänge während der Fahrt eines Aufzugs*, 2005/2006, Swiss Society of Engineers and Architects (SIA), Zurich / *Energy-related processes during the travel cycle of a lift.*