ENERGY MODELS FOR LIFTS
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Abstract
The intention of this paper is to explain some work which is being carried out at the International Standards Organisation level, to propose a simple energy reference model to support this work and to develop a simple energy model that could be employed in a traffic simulation program to predict energy consumption.

1 ISO Draft standard CD25745-1

A Working Group of an International Standards Organisation's Technical Committee (TC178/WG10) is developing a draft standard CD25745-1 "Energy performance of lifts, escalators and moving walks – Part 1 Energy and conformance". This standard will set down standard procedures to be used when making energy measurements and checking energy conformance. It will not grade, or provide energy certification for lifts, etc. as happens now for boilers, refrigerators, washing machines, etc.

At the current time the Working Group is proposing a simple pragmatic procedure that should be easy to carry out, uses readily available measuring equipment, is repeatable, and allows periodic conformance checks to be carried out.

2 Energy measurement for a Reference Trip Cycle

The proposal is to measure the energy taken by a lift during a reference trip cycle. The reference trip cycle comprises running an empty lift from the lowest landing to the highest landing and back again (see Figure 2). The lift will carry out its normal door operations at each terminal landing. These include opening, closing and dwell times. The energy consumed for at least ten cycles would be measured and an average energy consumption figure for a single reference trip cycle calculated.

Care will be needed to ensure all the energy used by the lift is included. For example sometimes the main power and the ancillary power (lights, fans, alarms, CCTV, trickle chargers, displays, etc.) are often supplied by separate feeders.

After the terminal landings cycling test the lift will be allowed to "rest" for five minutes at the lowest landing. An energy measurement will then be made with the lift maintained at the lowest landing. This will give the standby energy consumed. Green equipment manufacturers will thus be sure to reduce the idle power consumption by turning off all energy hungry lighting and controllers within this five minute period of grace.

The procedure just described requires a fairly sophisticated energy/power measuring instrument together with a skilled operator. So the second part of the proposed standard is to check conformity. This can be achieved by measuring the line currents at the same time as the energy measurements. Later an inexpensive, simple current meter (amp probe), applied by the service mechanic, can be used to detect any changes in the energy consumption. For example: the car might be become heavier if it was re-fitted with mirrors (more energy consumed) or the less energy demanding if the incandescent car lighting were to be replaced by low energy units (less energy consumed). Or the door timings might have changed.

The currents that are measured for the conformity check will not necessarily be exactly in proportion to the energy graph as the power factor (cosφ) values at the various car loadings will vary. However, as time passes as long as these values do not change then it can assumed that the energy consumption remains the same as when the energy was first measured and the conformance current readings taken.

This energy/power/current measurement procedure can be part of the final tests for a new lift and could be carried out for an existing lift on request.

3 Energy reference numbers

The lift now has two numbers: one for the energy consumed during a reference trip cycle and another for the energy consumed when on standby. These numbers apply only to the lift that has been measured and no other. No two lifts are the same even if they share the same rated load and rated speed and are in the same building. Obvious differences include: the travel distance between terminal landings, different door operating times, the counterbalancing ratio, the weight of the car, car balance, the type of guide shoes, roping factor, number of car entrances, drive system, etc, etc.

If a purchaser of a lift wishes to be seen to be "green", or is required to be by the terms of any building energy certification process, then the two reference numbers should be obtained before an order is placed. So where do these numbers come from ?

It is expected that suppliers will know their product sufficiently well (after all they have sized the drive machine and the indicated the supply cable sizes, etc.). It is also to be hoped that they will have energy models available for their products and thus be able to easily supply these two numbers. Of course the purchaser will be able to confirm them at the time of final test. Energy consumption could thus become a selection criterion between manufacturers.

4 A simple reference trip cycle model

So what does a simple energy model look like ? If a plot is taken of the power used by an empty car for a downwards trip it would look something like the Figure 1.

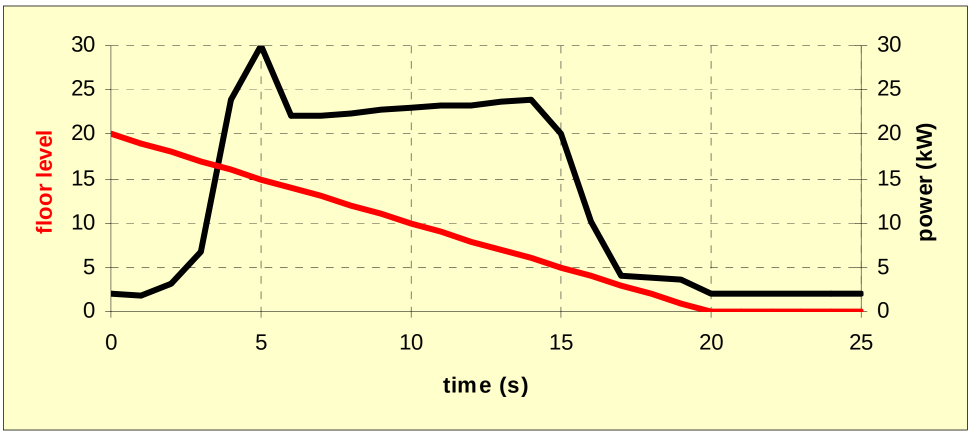

Figure 1 An actual trip profile for an empty car travelling down
(Source: Al-Sharif *et al*)

Figure 1 is based on real measurements.

Figure 2 is also based on real measurements, but a different lift. It shows an ISO reference trip cycle, ie: an empty car trip up and then down between terminal floors. The left Y-axis and the red line show the car movement. This lift has a rated load of 1500 kg, a rated speed of 4.0 m/s, is in a 24 floor building with a 62 HP hoist motor. The right Y-axis and the black line shows the power consumed. The plot has been idealised for simplicity as the actual plot will have irregularities in it similar to those shown in Figure 1. The values are from the 0% car load row in Table 1.

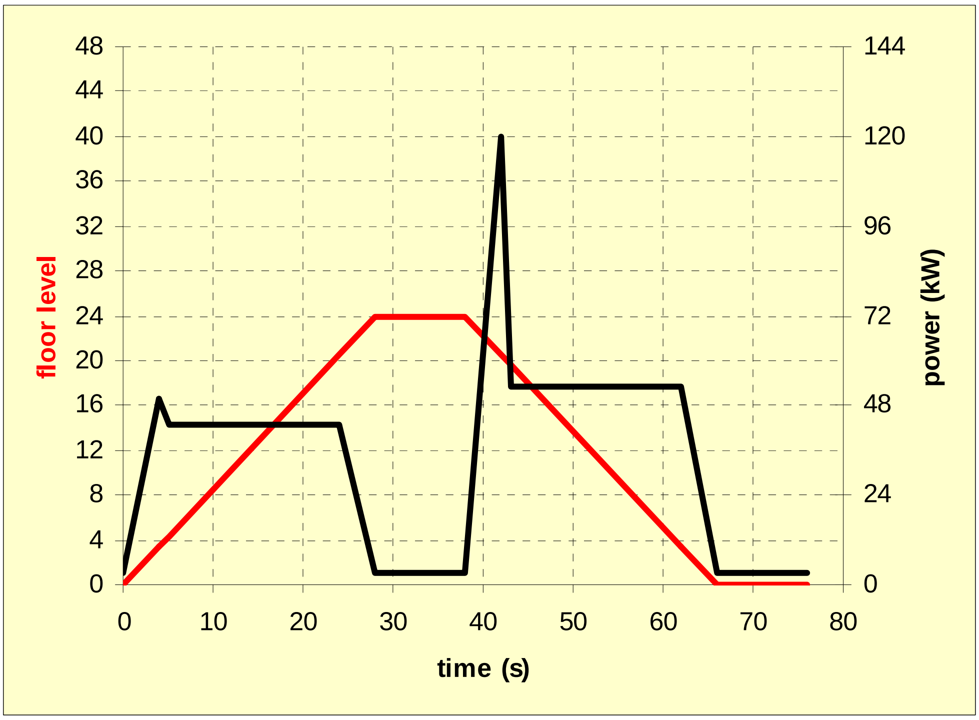

Figure 2 Idealised reference trip cycle

The reference trip cycle has four main parts:

(1) power consumption for an empty car up (28 s)
(2) door operations at the highest landing (10 s)
(3) power consumption for an empty car travelling down (28 s)
(4) door operation at the lowest landing (10 s)

The first part is further subdivided. There is a peak power on start up, which reduces to the running power when rated speed is reached. At the end of the running time the power falls to the idle power (3.0 kW). Remember idle power is not standby power.

The energy consumed is the area under the graph in Figure 1, in kilowatt seconds (kWs). This can be simply calculated as a set of triangles and rectangles[1] and is equal to 2,456 kWs (plus 60 kWs idle energy) giving 2,516 kWs (0.7 kWh) total energy consumed per reference trip cycle. As the reference trip cycle occupied 76 seconds, if cycling had continued for one hour the energy consumed would be 33.1 kWh (cost about £3.31).

[1] A copy of the energy model spreadsheet can be obtained by sending a blank CD in stamped envelope to: PO Box 7, Sedbergh, LA10 5GE.

The example shown in Figure 2 is unique as the time for the full travel distance is 28 seconds. If the travel distance were different, a different result would be obtained.

6 Obtaining data for the model

The data required is:

Time to reach peak power up and down
Time running at rated speed (at rated power)
Running power up and down empty
Peak power up and down empty
Door timings

6.1 Times

The time to reach the peak power and the time to reach running power can be measured. If these values are available they can be used in the model. If not an estimate will need to be made.

The idealised graph in Figure 2 assumes the time to reach the peak from starting is half the time to reach the rated speed and the time from the peak to reach the running current is 12.5% of the time to reach the rated speed.

The time (*tvm*) to reach rated speed (*vm*) is given by:

$$tvm = \frac{vm}{a} + \frac{a}{j}$$ (source CIBSE Guide D, A-30)

where:
a is the value for acceleration (m/s^2)
j is the value for jerk (m/s^3)

If values for a and j are not available, then use 0.8 m/s^2 and 1.2 $m/^3$ respectively.

6.2 Running power

If the data for the power used for an empty car running up and down between terminal floors is not available what can be done ? Several methods can be used to estimate the profile.

(a) Calculation method 1: the motor rating is known

In the example shown in Figure 2 the motor rating was 46.3 kW (62 HP).

The flight time between terminal landings is 28 s, ie: 58 s total running time. If the motor ran for 58 s at its full rating it would consume 46.3 × 58 = 2,685 kWs.

(b) Calculation method 2: the lift specification is known

In the example above the rated load was 1500 kg and the rated speed 4.0 m/s. This gives an ideal motor rating of 30 kW. Assume 70% efficiency gives the motor rating as 42.9 kW. If the motor ran for 58 s at its full rating it would consume 42.9 × 58 = 2,488 kWs.

(c) Calculation method 3: the running current is known

If the running current is measured as 58 A, assuming unity power factor the power rating of the motor is

$$\sqrt{3} \times 415 \times 58 = 41.7 \text{ kW}$$

If the motor ran for 58 s a full rating it would consume 41.7 × 58 = 2,419 kWs.

The three calculations rely on significant assumptions, but give estimations of the energy consumed to the profile of Figure 2.

6.3 Starting power

If this is known it should be used. If it is not then for a DCVV use twice the running power and for an ACVV use 1.5 times the running power. The energy consumed in the peaks is small compared to the energy consumed when running so these estimates are unlikely to introduce significant errors.

7 Traffic patterns

No one can predict the usage pattern of a lift. It is a bit like predicting how the stock market will perform. Many assumptions are made by experienced traffic designers when sizing a lift installation. This is why some naïve developers get it wrong as they lack that experience.

Traffic simulators are used to study the behaviour of a particular design. Thus it would be useful to be able to study the energy behaviour at the same time. A simple model is proposed.

A lift traffic simulator "knows" the passenger load in the car, the direction of travel, the number of passengers entering/leaving, the travel distance, door timings, etc. If the power used for each individual car load and each individual direction of travel were known then the simulator could estimate energy consumption.

8 An energy model for a traffic simulator

To insert an energy model into a traffic simulation program requires data such as that shown in Table 1. This table is for the example installation considered in Figure 2. It shows the power required for starting and running for the range of car loads from 0% to 100% in both directions of travel. It is unlikely that such detail would be available. In fact this table is only valid for the entries shown in the grey cells of the table. These entries were obtained from the record made[2] when the lift was tested in 1993.

The data has been idealised and the values rounded to make the arithmetic easier. A linear relationship is shown between the grey cell entries. This is an assumption, in practice the relationship will be nonlinear. Thus a simple table can be developed.

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[2] The document used was BS5655-10: 1986 "Certificate of test and examination for lifts" and the data was recorded in Section A5(c) "Measurement of the electrical system" for empty, balanced and fully loaded cars. The latest test documents (PAS32/BS8486) do not record such data).

It is interesting to note that at balanced load (50%) the power taken is 13 kW. This is made up of 3 kW idle power to the controllers and ancillaries and 10 kW to overcome inefficiencies. This implies the lift system is some 78% efficient (36.3/46.3).

Table 1: Data from actual installation used to obtain Figure 2

Car load (kg)	Car load (%)	Power running down	Power starting down	Power running up	Power starting up
0	0	53	120	43	50
75	5	49	118	40	55
150	10	45	116	37	60
225	15	41	114	34	65
300	20	37	112	31	70
375	25	33	110	28	75
450	30	29	108	25	80
525	35	25	106	22	85
600	40	21	104	19	90
675	45	17	102	16	95
750	50	13*	100	13*	100
825	55	16	97	17	103
900	60	19	94	21	106
975	65	22	91	25	109
1050	70	25	88	29	112
1125	75	28	85	33	115
1200	80	31	82	37	118
1275	85	34	79	41	121
1350	90	37	76	45	124
1425	95	40	73	49	127
1500	100	43	70	53	130

* 3.0 kW is controller plus ancillaries =10 kW for inefficiency.

Table 2: Data used to construct Figure 3 (figures rounded)

Floor	Number of passengers			% car load	Peak power starting	Running power	Total door operating time
	In car on arrival at floor	Leaving car at floor	In car on departure from floor				
0	0	0	20	100	130/98*	n/a	0
1	20	2	18	90	124	45	8
4	18	3	15	75	115	33	9
8	15	1	14	70	29	n/a	7
10	14	3	11	55	17/13*	n/a	9
11	11	1	10	50	100	13	7
14	10	4	6	30	80	25	10
18	6	2	4	20	31/23*	n/a	8
19	4	2	2	10	60	37	8
22	2	2	0	0	120	53	8

Other data are: Time to reach rated speed: 4.0 s. Passenger transfer time 1.0 s per passenger. Flight times: one floor – 6.0 s, two floors – 8.0 s, three floors – 9.0 s, four floors – 10.0 s. Door open and door closing times: 3.0 s each. * Single floor jumps – peak not reached.

9 Examples of an energy model in a simulation program

9.1 Uppeak traffic

Consider Figure 3. This shows the spatial movements of the example lift shown in Figure 2 during the morning uppeak traffic demand. Table 2 gives the data used.

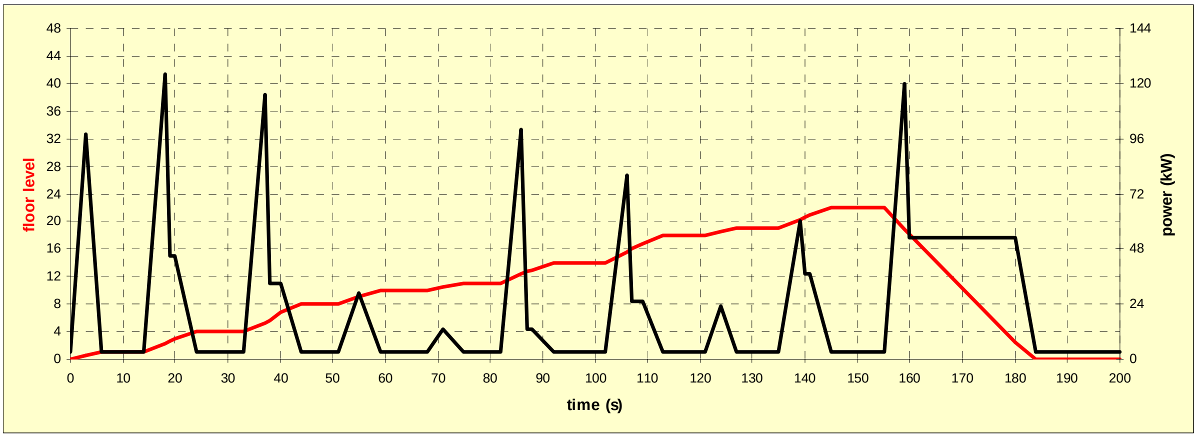

Figure 3 Power profile for a typical uppeak traffic pattern

The lift leaves Floor 0 with 20 passengers and calls at nine floors with various number of passengers alighting. Thus the load reduces until the last passengers exit at Floor 22. The lift then returns empty to Floor 0. Note the balance load is achieved as the lift leaves Floor 11.

Where the lift only moves one floor, eg: 0>1, 10>11, 18>19 the graph shows a reached peak power only as rated speed is not reached. Where the lift moves two floor, eg: 8>10 rated speed is just reached before the slow down sequence is initiated. In all other cases the lift reaches rated speed as indicated by the step in the profile, although it may only be for a short time, eg: 1>4, 19>22.

The energy profile has been idealised for the purpose of illustration. This would not be necessary in a simulation program as the actual profiles can be calculated. Once again the energy consumed is the area under the profile. This can be easily calculated by a simulation program.

10 Regenerative systems

10.1 ISO reference trip cycle

What would a regenerative profile look like for the ISO reference trip cycle ? Using data given in a paper by Al-Sharif, Peters and Smith for a lift with a rated load of 1800 kg (counterbalanced at 42%) and rated speed of 4.0 m/s, then Table 3 can be generated.

Table 3 Data for a regenerative drive system

Car load (kg)	Car load (%)	Power running down	Power starting down	Power running up	Power starting up	Assumed power on starting down
0	0	23	30	3.0	-9	n/a
450	25	12	21	8.8	0	13
900	50	6	17	13	5	10
1350	75	-5	6.6	27	18	4.4
1800	100	-12	2.7	31	31	1.8

The numbers are rounded for simplicity. The idle power is 2.0 kW.

Using only the data for the empty car (0%) then Figure 4 can be obtained for an ISO reference trip cycle of an empty car travelling up, pausing and then travelling down.

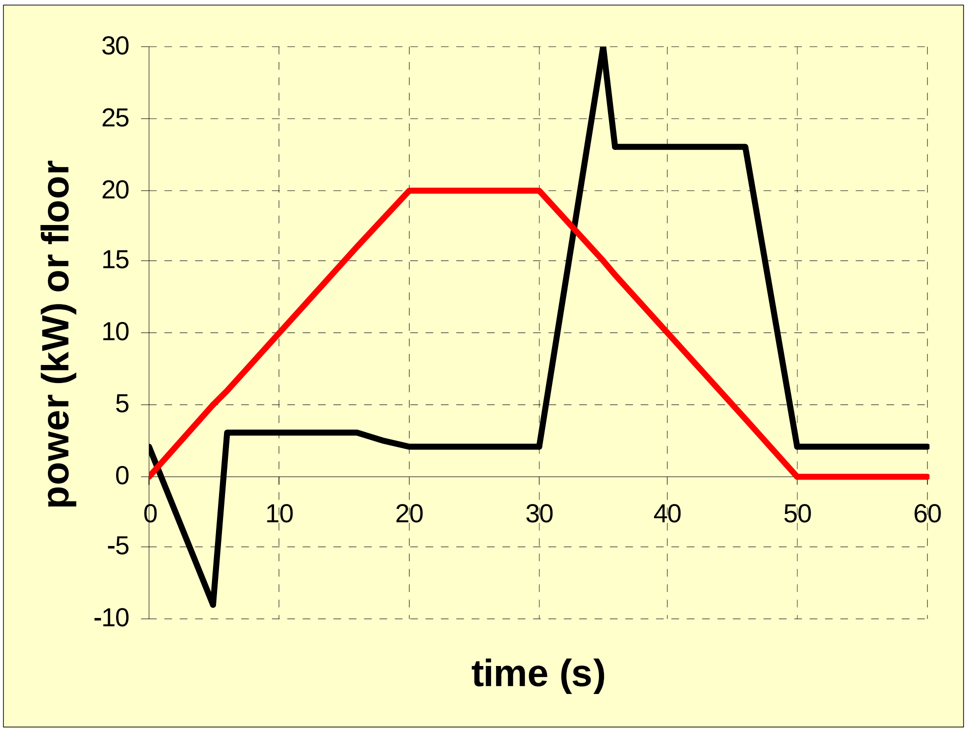

Figure 4 Reference trip cycle for a regenerative drive system

The benefits of regeneration can be seen as less energy is used to move the empty car on its upwards trip.

10.2 Down peak traffic

The benefits of regenerative systems are most evident where a heavy car is moving down, or a light car moving up. This is particularly so for the end of day, down peak traffic pattern, where cars load to capacity. Using the Al-Sharif data from Table 3, Figure 5 can be drawn.

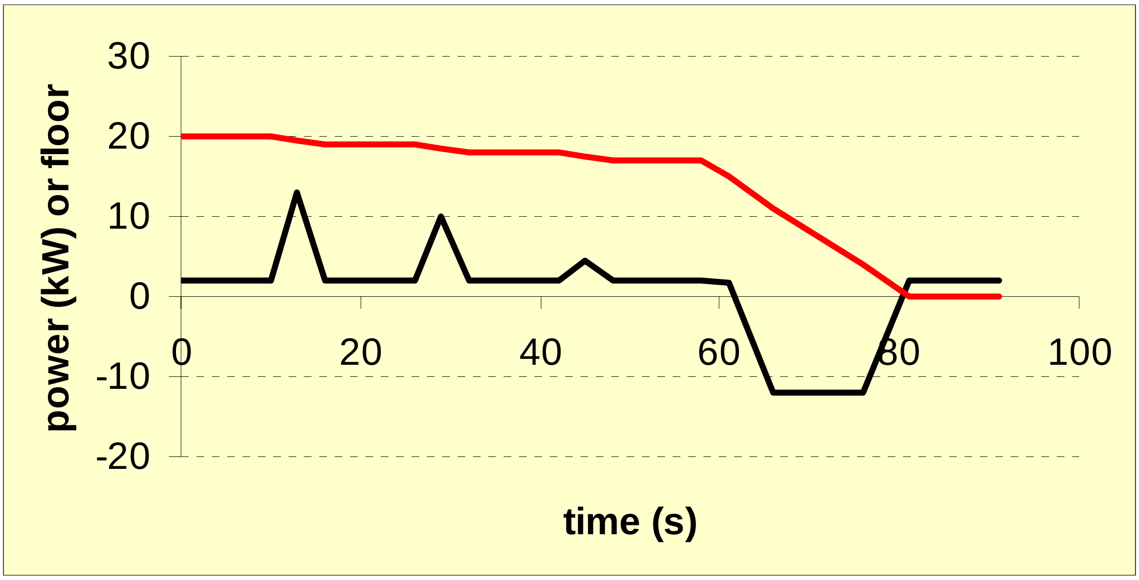

Figure 5 Power profile for a typical down peak traffic profile

The graph shows a lift loading at Floor 20 with six passengers, which takes 10 seconds including door times. The lift then successively calls at Floors 19, 18 and 17 loading six passengers each. Because the flight time between two adjacent floors is only six seconds the peak starting currents are not reached and are estimated at 2/3rds of the measured peak (see last column of Table 3). Once the lift leaves Floor 17 it regenerates power back into the mains supply. It should be noticed that of the 80 seconds from loading at Floor 20 until the lift arrives at Floor 0, the lift is only moving for 40 seconds.

11 Discussion and conclusions

How accurate are the methods described and how accurate do they need to be ?

The method for taking energy measurements of an actual system using the ISO reference trip cycle will be as accurate as the instruments used and the skill of the user. The same conditions apply to the current measurements made. The two measurements obtained should give a good view of how well a lift is performing at the time of measurement and over time.

Prediction of the two ISO numbers is not difficult. The simple energy model proposed based on the ISO reference trip cycle, relies on a number of simplifications, as discussed in Section 6. Errors in the values used will affect the shape of the power/energy profile as shown in Figure 2. However the energy used in the peaks is small compared to that used when the lift is running. As the running power is likely to be known with good accuracy, little error should occur. In any case lift suppliers usually know their product very well and will have accurate values for all these parameters.

Energy usage prediction is much more difficult. The simple model proposed can be employed to calculate energy usage. More data is required, which used to be collected when a lift was commissioned (tested/adjusted). This data (as shown by the grey cells in Table 1) enables an interpolation on a linear basis. This is not strictly correct as electric motors are magnetic devices and exhibit significant nonlinearities. Using data such as that shown in Section 9 allows a reasonable attempt to be made to predict the energy used for a SPECIFIC traffic pattern. A striking feature is how little energy is used. It is important to note that the energy profile varies with the direction of travel and is not symmetrical, ie: another nonlinearity.

Section 10 looks at a regenerative system using data in the public domain for four levels of car loading. Figure 4 shows what an ISO reference trip cycle, for an empty car, would look like. Figure 5 shows the energy profile for a SPECIFIC traffic pattern representing down peak traffic. Of significance is the lower energy usage in both cases. Both cases have been "hand drawn", but if the proposed model is embedded in a simulation program, then a more precise calculation can be made, which will be as accurate as the data provided.

The energy measurement of building services is being required more and more by various regulations, for example, in order to comply with the energy certification of buildings. Modern lifts (and some older ones too) are already very efficient, especially those based on counterbalanced systems. However, it is wise to prove this to energy inspectors and standard methods of energy measurements, conformance checking and modelling are necessary to do this.

The answer to the questions posed is "accurate enough" !

References

Al-Sharif, L., Peters R. and Smith, R: "Elevator Energy Simulation Model", IAEE, Elevator Technology 14, April 2004.
Barney, G.C.; CIBSE Guide D: 2005: "Transportation systems in buildings", Appendix A, September 2005.

Warning

The data used and the graphs plotted are based on real systems, but they have been modified and the numbers rounded to illustrate the discussion and close examination may reveal anomalies.