Energy Efficient Buildings
Assessing The Impact of Lifts

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Abstract. As the impact of climate change becomes ever more visible, society appears at last to be reacting and making changes aimed at mitigating its impact and protecting our established ways of life. Most if not all human activity affects our planet, and the creation, operation, modernization, and replacement of buildings is no exception.

The lift industry therefore has an important part to play in minimizing its impact on our climate; the creation of new lift equipment consumes energy which is quantified by its embodied carbon credentials, whilst the use of lifts consumes energy characterised by its operational carbon credentials. These carbon credentials play a key part in the assessment of a building's energy performance and as an industry we now need to recognize this and refine both the processes and the accuracy with which we model the impact.

This paper explores some of the current guidance and assessment methodologies touching on such established documents as the British Standard BS EN ISO 25745 [1]. Application of these methodologies will be reviewed against a real-world case study, and conclusions and recommendations presented on how the industry might refine future assessments towards more realistic results.

1 BACKGROUND

Whilst the debate on the causes of changes to our climate may continue for some time, the fact that our climate is changing appears to be undeniable. This year's news seems frequently to feature stories from around the world reporting on the negative impacts of changing climate; from severe wildfires in California and the Mediterranean, to catastrophic flooding in Australia, to the driest July in the United Kingdom since 1935 [2].

Over recent years society and our governance has started to act introducing rules and regulations aimed at mitigating the impact of climate change. The UK introduced the Climate Change Act [3] in 2008 setting a legally binding target for 2050 to reduce greenhouse gas emissions by at least 80% compared to 1990 levels. Good progress is being claimed with a 38% reduction in UK emissions between 1990 and 2019 [4], however measured against the growing evidence and concern this was seen to be insufficient and in June 2019 the UK government went further with an amendment to the Climate Change Act setting a legally binding target to achieve net zero greenhouse gas emissions from across the UK economy by 2050. The scale of the challenge is clear to see, and the impact of failure for future generations unthinkable.

This paper however is not intended to spread doom and gloom, nor to expound on the issue of climate change. The scale of the challenge is daunting, and it is often hard to see the wood for the trees and to see what part, however small, we can play. This paper's intent is to provide some comment, guidance and opinion on where the lift and industry "fits" within the challenge and how best might our industry respond and play our part in driving down damaging emissions.

Back in 2015 the United Nations (UN) published their 17 Goals Sustainable Development Goals (SDG) [5], as shown in Figure 1 below.

Figure 1: United Nations 17 Sustainable Development Goals (SDG)

These goals, shared by all United Nations member States, are intended to provide a blueprint for peace and prosperity for people and the planet, now and into the future. They were and remain an ever more urgent call for action by all countries, and in the UK one of the major catalysts for the development of methodologies to achieve the government's net zero 2050 emissions target.

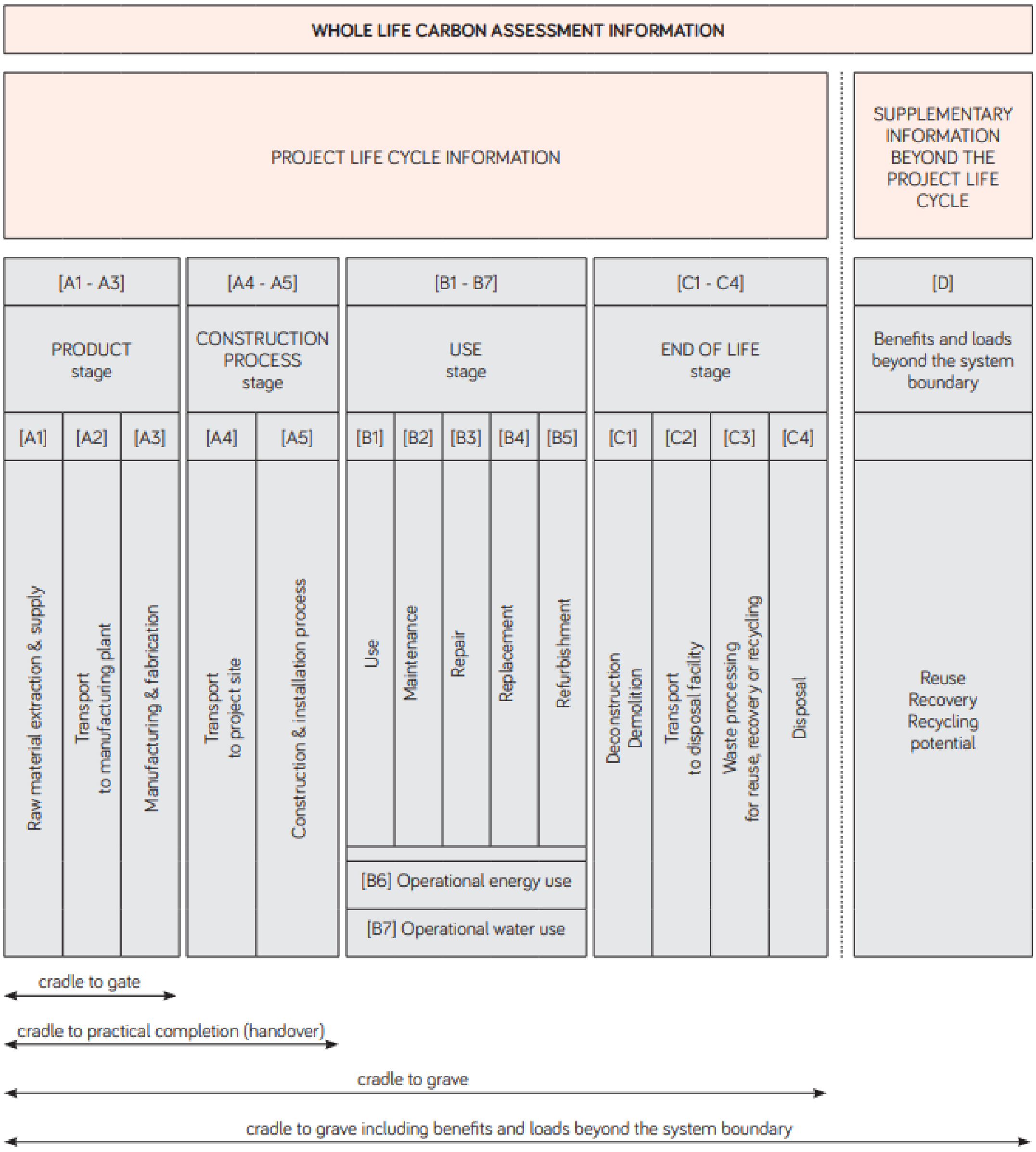
Buildings are complex with many interrelated elements such as structure, façade, mechanical systems, electrical systems, clean and wastewater systems, fire protection systems, and of course lift systems. The manufacture, shipping, installation, operation, removal and modernization of each of these systems produce damaging carbon dioxide (CO_2) emissions. Reducing the volume of CO_2 (typically referred to in this context as simply carbon) emitted during the lifetime of a system is the ultimate goal.

The carbon created over a system's lifetime is referred to as Whole Life Carbon (WLC) and in itself is a complex concept. It can typically be thought of as comprising two fundamental components:

- Embodied Carbon – the total CO_2 emitted in producing materials, estimated from the energy used to extract and transport materials as well as from the manufacturing process itself.
- Operational Carbon – the total CO_2 emitted due to the building's energy consumption in use.

2 ASSESSMENT METHODOLOGIES

In the UK many respected bodies have responded to the government's net zero legislation with guidance and methodologies for the assessment of carbon emissions. Key amongst these is the Royal Institution of Chartered Surveyors (RICS) methodology for undertaking detailed carbon assessments for buildings (RICS Whole life carbon assessment for the built environment professional statement 2017) [6]. Figure 2 below illustrates the modular structure of the RICS PS, which also aligns with the recommendations set out within BS EN 15978.



Modular reporting structure of BS EN 15978 as used in RICS PS
Module A: Product and Construction stages; Module B: In use; Module C: End of Life; Module D: potential benefits through reuse or recycling.

Figure 2 – RICS PS Whole Life Carbon Assessment Information

This approach covers both operational carbon in terms of energy use and water use (modules B6-B7), and embodied carbon emissions (modules A1-A5, B1-B5, C1-C4 and D). It is of note that module D provides opportunity for "credit" related to reuse or recycling of materials at end of life, supporting the circularity concept of maximizing the sustainability value of created materials.

For buildings WLC is typically reported in units of $kgCO_2e/m^2$ Net Internal Area (NIA), where CO_2e is carbon dioxide equivalent, which is a measure of all produced greenhouse gases associated with the system being presented in terms of the amount of pure CO_2 that would create the same amount of warming.

The carbon cost of materials is commonly assessed using Environmental Product Declarations (EPDs) which provide a range of data including embodied and operational carbon. The EPD process is strictly regulated and requires third party ratification. Assessments typically have a validity period beyond which a re-assessment must take place.

3 CASE STUDY

Given the diverse range of materials in a lift, and the global nature of the lift industry's manufacturing plants and installed product base, the challenge of accurately predicting and/or comparing the carbon cost of lifts may at first seem somewhat daunting. However, when viewed through the lens of "don't let perfect be the enemy of good" and an acceptance that it can never be 100% accurate, a set of necessary assumptions unlock the process and allow some 'compare and contrast' analyses to be completed.

Over the past few years, the lift industry has taken good strides in advancing the level of information published as EPDs. ISO 14026 and EN 15804 are typically used as standards to define core product category rules (PCR) for construction products such as lifts. The PCR defines a consistent approach for assessment and describes which stages of a product's life cycle should be in the EPD; this consistent approach is intended to provide the ability for different products to be compared in terms of WLC, with the ultimate goal that products with a lower carbon footprint are selected in preference to those with a higher impact..

However, this 'compare and contrast' process needs care in application; the data is detailed and complex and needs to be reviewed and interpreted by skilled practitioners. It is important to ensure the products being compared are truly equivalent. For example, it would not be appropriate to compare a 1000 kg, 1.0 m/s, 15 m travel, machine roomless lift with a 1600 kg, 4.0 m/s, 80 m travel, machine above lift; the speed difference will require different drives and machines, the travel difference will create longer guide rails, ropes and travelling cables, and the number of stops will create the need for more landing entrances. It is even important to review the assumptions made in terms of the electricity supply mix applied to the operation and manufacturing modules, and for this some understanding of the geographical location of manufacture and installation is required.

To provide some form of normalization a key PCR defines the concept of the Functional Unit (FU), a measure of the transportation of a load over a distance expressed in tonne (t) over a kilometre travelled (km), where:

$$FU = \%Q \times S_{RSL}$$

Where:

> %Q is the average load (t) determined by selecting the appropriate usage category according to ISO 25745-2 Table 1 and multiplying the rated load Q by the applicable average load percentage as per ISO 25745-2 Table 3.

And:

> S_{RSL} is the distance travelled over the lifetime of the equipment determined by the average travel distance (ISO 25745-2 Table 2) x number of trips per day (n_d) (ISO 25745-2 Table 1) x number of operating days per year x service life of the equipment in years.

For example, consider a 1600 kg lift serving 9 floors over a travel of 40 m. The equipment has a predicted service life of 20 years, 365 days per year operation, and operates under a usage category 4:

$$FU = \%Q \times S_{RSL}$$

$$FU = (0.035 \times (1600/1000)) \times ((0.44 \times (40/1000)) \times 750 \times 365 \times 20)$$

$$FU = 0.056 \times 96{,}360$$

$$FU = 5{,}396 \text{ tkm}$$

To illustrate the challenges of comparing and contrasting products from different manufacturers the author conducted an informal review of published EPDs for similar mid-range machine roomless lifts from three major suppliers. Extracted in the table below are key data from the EPDs for the manufacturing processes (A1 + A2 + A3) and the operational energy in use (B6). The environmental impact is represented by the Global Warming Potential (GWP).

Table 1 EPD - Comparison Electric Traction Machine Roomless Lift

Supplier	**Representative Unit**	**Declared Functional Unit [tkm]**	**Upstream & Core Environmental Impact GWP [kgCO$_{2eq}$/tkm]**	**Energy Consumption In Use GWP [kgCO$_{2eq}$/tkm]**	**Total Considered GWP [kgCO$_{2eq}$]**
1	1000 kg 1.6 m/s 12 stops 35 m travel Usage Class 4 Service Life 20 years	1690	21.706E+00	7.89E+00	13,356
2	1000 kg 1.6 m/s 8 stops 21 m travel Usage Class 4 Service Life 20 years	3035	3.8767E+00	8.62E+00	37,928
3	630 kg 1.0 m/s 5 stops 12 m travel Usage Class 3 Service Life 25 years	761	11.232E+00	5.11E+00	12,437

So which supplier has the most environmentally friendly product? Well, it's hard if not impossible to say, at least from the data analyzed in this exercise. Whilst key characteristics such as rated load, speed, usage class and service life are the same for supplier #1 and #2, the travel and stops are different. Supplier #3's published data did not seem to include a 1000 kg lift of any configuration, so a smaller and slower 630 kg lift was selected, with a lower travel, different usage class, and longer service lifts. The EPD process requires a representative equipment configuration applied to a theoretical lifetime duty cycle. Unless the equipment and lifetime duty cycle, i.e. the Functional Unit (FU), is the same or similar, valid comparisons are hard to draw.

Perhaps a more transparent comparison, for the energy in use module at least, can be provided by the ISO 25745-2 methodology for the calculation and classification of energy performance for lifts. This standard defines the methodology for the classification of energy performance for a lift. It is somewhat simplified by necessity, and it is of note that the method is intended to only be applied to single lifts and therefore any energy efficiencies realized in dispatching logic across a group of lifts is not recognized. Regenerative drive systems are also not clearly recognized by the method albeit some reference is made to a slightly different method for calculating energy for a lift that draws some or all of its energy from an energy storage system. It is also interesting to note the standard draws the reader's attention to the fact that there might be a deviation between calculated values and measured on site values in use, and that if this deviation is greater than 20% (a seemingly large factor), an investigation should be carried out.

The methodology set out in ISO 25745-2 is detailed and needs care in application but is logical and robust. It considers the following key elements, and the reader should consult the standard for the detail behind each one:

- Usage category and number of starts per day
- Average travel distance
- Average running energy per metre travel
- Running energy of an average cycle with an empty car
- Load factor and average car load
- Non-running (idle/standby) energy consumption
- Ratio of idle, 5 min standby, and 30 min standby modes
- Running time per day

Application of the above derives the calculated total energy consumption per day, which can then be converted to estimated annual energy consumption. Care should be taken in considering the number of days the lift will operate, for example in an office building it may be appropriate to consider the weekend as a period of predominantly standby mode energy consumption.

The application of the ISO 25745-2 methodology typically results in a table of results for a lift system which is then compared against the area of the building to derive a kWh/m^2/year. An example of such analysis can be seen below and represents a twenty-floor office building development in London.

Figure 3 Case Study ISO 25745-2 Energy Analysis

Category data	Symbol	Units	PL01/FL	PL02/EL	PL03	PL04	PL05	PL06	PL07/EL	PL08/FL	GL01	GL02	CL01
Category			5	5	5	5	5	5	5	5	4	4	3
Median number of trips/day for category (BS EN ISO 25745-2, Table 1)	nd		1500	1500	1500	1500	1500	1500	1500	1500	750	750	300
Total operating days per year (BS EN ISO 25745-2, Table A1)			260	260	260	260	260	260	260	260	260	260	260
Lift parameters, measurement data													
Rated load	Q	kg	1275	1275	1275	1275	1275	1275	1275	1275	2500	2500	1275
Rated speed	v	m/s	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.6	1.6	1
Acceleration	a	m/s^2	1	1	1	1	1	1	1	1	1	0.9	0.9
Jerk	j	m/s^3	1	1	1	1	1	1	1	1	1.2	1	1
Door times	t_d	s	5	5	5	5	5	5	5	5	5	5	5
Total travel distance	s_{rc}	m	55.3	55.3	55.3	55.3	55.3	55.3	55.3	55.3	55.3	55.3	11.85
Reference cycle energy	E_{rc}	W·h	190	190	190	190	190	190	190	190	400	400	115
Idle power	P_{id}	W	260	260	260	260	260	260	260	260	370	370	220
Standby power	P_{st}	W	200	200	200	200	200	200	200	200	280	280	200
Average trip distance	s_{av}	m	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	24.33	24.33	5.81
Ratio average travel (BS EN ISO 25745-2, Table 2)	k_{av}	%	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.44	0.44	0.49
Percentage rated load (BS EN ISO 25745-2, Table 3)	(%Q)	%	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	2.2	2.2	4.5
Load factor (50% balance)	k_l	%	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.96	0.96	0.93
Idle percent (BS EN ISO 25745-2, Table 4)	R_{id}	%	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.45	0.45	0.36
Standby percent (BS EN ISO 25745-2, Table 4)	R_{st}	%	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.55	0.55	0.64
Energy calculation													
Specific energy	E_{spc}	mW·h/kg·m	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.45	1.45	3.81
Running time per day	t_{rd}	h	7.14	7.14	7.14	7.14	7.14	7.14	7.14	7.14	4.72	4.77	1.07
Standing time (the time the lift is not running)	t_{nr}	h	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	19.28	19.23	22.93
Time to travel the average travel distance	t_{av}	h	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	22.6	22.9	12.8
Running energy/day	E_{rd}	W·h	48101	48101	48101	48101	48101	48101	48101	48101	63619	63619	7829
Standing energy/day	E_{nr}	W·h	3,798	3,798	3,798	3,798	3,798	3,798	3,798	3,798	6,180	6,164	4,751
Total energy/day	E_d	W·h	51899	51899	51899	51899	51899	51899	51899	51899	69799	69783	12580
Total energy/day		kWh/day	51.9	51.9	51.9	51.9	51.9	51.9	51.9	51.9	69.8	69.8	12.6
Total energy/year		kWh/year	13493.7	13493.7	13493.7	13493.7	13493.7	13493.7	13493.7	13493.7	18147.7	18143.5	3270.8

Total Energy/Year (kWh/yr)	147512
Area (NLA m^2)	19525
$kWh/m^2/yr$	**7.56**

Note:

1. Lift energy calculated using ISO 25745-2 (2015).
2. The reference cycle energy, idle and standby power are assumed data.
3. Total energy per year based on 5 days week.

This analysis indicates a theoretical energy consumption of 7.6 kWh/m^2/yr. The daily predicted energy consumption of the main group of eight passenger lifts is 8 x 52 = 416 kWh.

However, within the analysis are a number of significant assumptions; reference cycle energy, standby power, and idle power are all assumed for the proposed equipment. This, allied to the fact that the methodology takes no account of group control logic, or the potential benefit of regenerative drives, may serve to make the assessment of limited value, especially when considered in the real-world context of trying to accurately predict actual energy consumed for a building yet to be built.

But accurate prediction is precisely what our industry is being tasked to provide. Recent changes in legislation, combined with a market appetite to provide and occupy demonstrably energy efficient premises, are placing a growing focus on delivering buildings that perform as predicted. Initiatives such as the NABERS scheme and its associated Design for Performance (DfP) process [7] are becoming typical requirements on large commercial office buildings in the UK, and include a requirement to audit the actual real-world energy usage regularly to ensure it remains no more than that predicted. The need therefore to be able to predict energy usage more accurately is coming at us fast.

It therefore seems to the author that we might explore alternate methods of predicting energy consumed by lift systems, perhaps by utilizing existing simulation tools already to hand.

Figure 4 [8] below illustrates an established full day demand profile for a passenger lift and might be an appropriate starting point to define the demand, at least in the current absence of more real-world data from the industry.

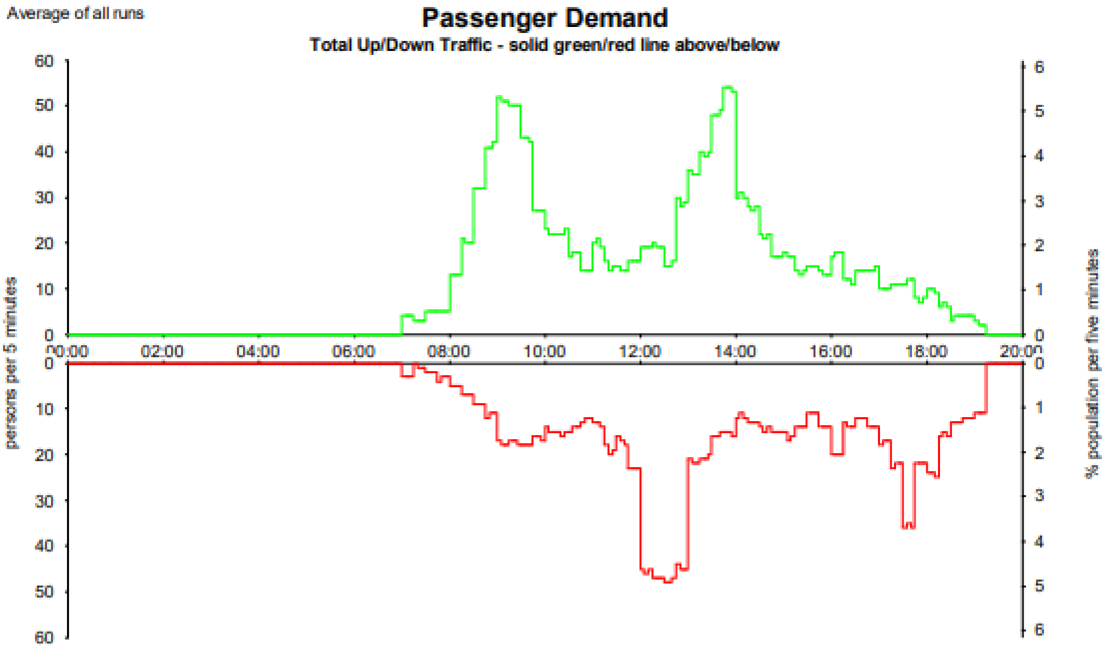
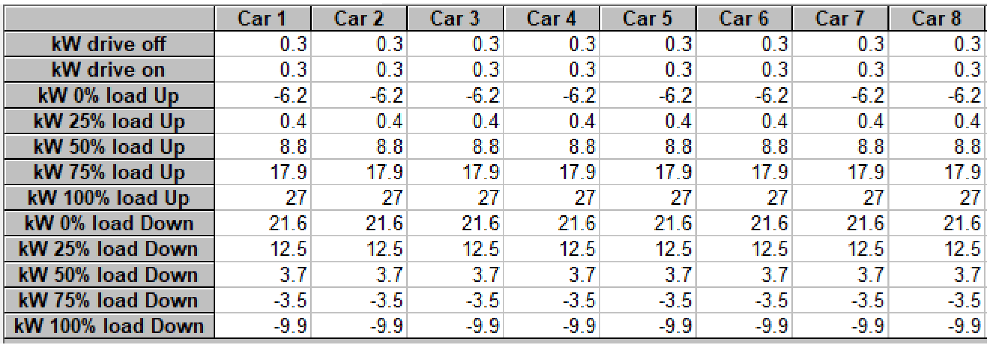


Figure 4 Siikonen Full Day (24-hr) Office Demand Template

Some lift traffic analysis software already contains energy "modules" which model the electrical characteristics of lift equipment. Figure 5 below illustrates an example of such data generated for the eight passenger lifts in this case study and shows predicted kW values for both running and standby modes along with estimates of power requirements under different loads whilst running in different directions. Figures for standby and idle are assumed and typical.



	Car 1	Car 2	Car 3	Car 4	Car 5	Car 6	Car 7	Car 8
kW drive off	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
kW drive on	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
kW 0% load Up	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2
kW 25% load Up	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
kW 50% load Up	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
kW 75% load Up	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
kW 100% load Up	27	27	27	27	27	27	27	27
kW 0% load Down	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6
kW 25% load Down	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
kW 50% load Down	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
kW 75% load Down	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
kW 100% load Down	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9

Figure 5 Electrical Data Input To Energy Simulation Model

It's of note that some of the running values are negative which on closer inspection indicate the system running in a regenerative capacity, essentially pushing energy back into the system. This is particularly prevalent with a light car running up when the heavier counterweight is overhauling the motor, and with a heavy car running down journey where the heavier car is overhauling the motor.

This approach seems therefore to offer some opportunity in terms of aligning the analyses with a more real-world scenario, especially when one also considers the embedding of this data in a traffic simulation tool which might also account for efficiencies in dispatching that should be inherent in smart control systems such as hall call allocation.

Running the simulation 10 times, each time with a randomized passenger demand pattern, elicits the results shown in Figure 6 below. It is very relevant to note that in building this model, the typical daily population has been set at 70% of the design population; this approach accords with the recommendations set out in NABERS.

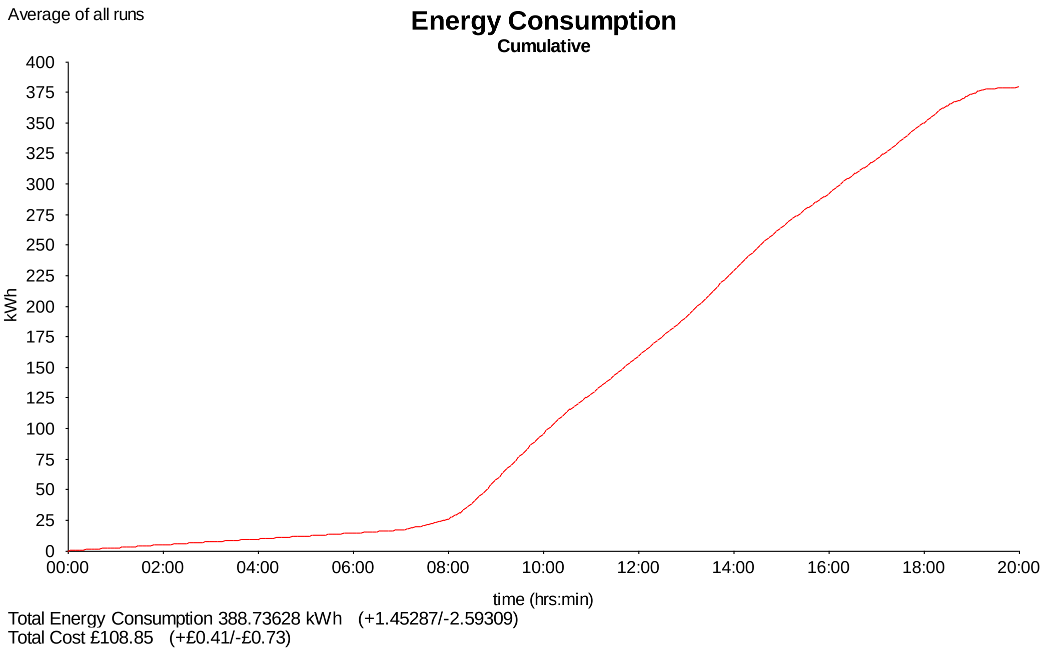
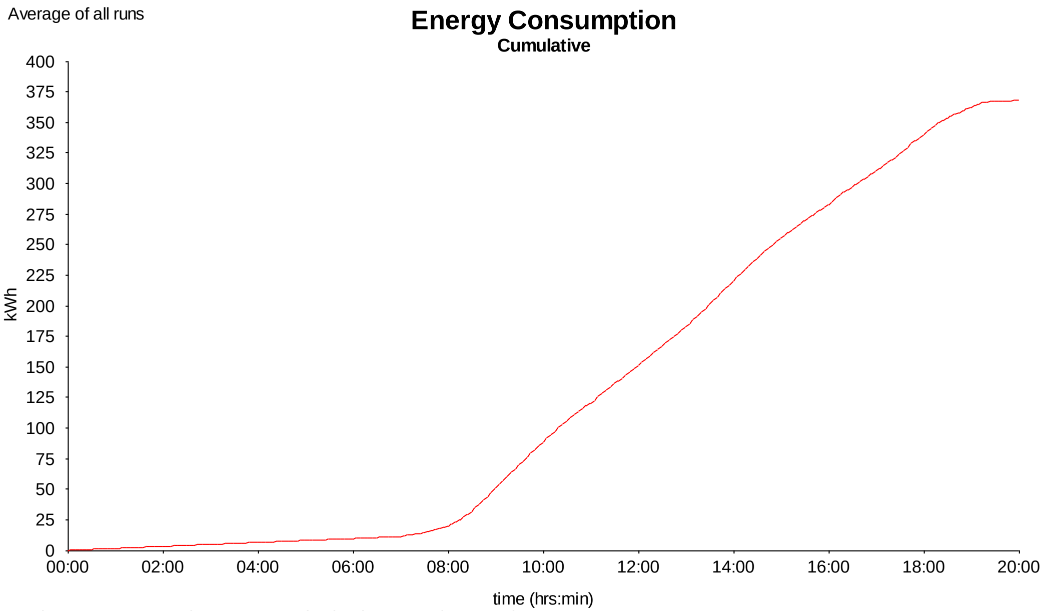


Figure 6 Simulation Model Daily Energy Use

The total daily energy consumption of the eight passenger lifts is modelled to be 389 kWh, a 6.5% reduction on the 416 kWh predicted by the ISO 25745-2 methodology.

If one reviews further the proposed 24-hour demand model it is of note that a significant period of time is spent with no or very low demand, i.e. the lifts are sat stationary in standby or idle mode. The assumed and actual kW rating of standby and idle mode are therefore very significant (particularly in residential applications where the percentage time spent stationary can far exceed that in an office). If one were to adopt a more aggressive assumption in the case study, and model say 150W idle and 200 W standby, the predicted daily energy consumption of the system falls again to 374 kWh, now a 10% reduction from the ISO modelled figure, see Figure 7 below.



Total Energy Consumption 374.19259 kWh (+1.45542/-2.60335)
Total Cost £104.77 (+£0.41/-£0.73)

Figure 7 Simulation Model Daily Energy Use (Optimised Standby/Idle)

There is also a growing trend within office design for building amenities, aimed at attracting people back into the office. These amenities have the potential to create additional, disruptive demand on the passenger lifts, and to a lesser extent on the goods lifts. In an ideal energy model this demand would also be simulated however it is common for the type of amenity to be unknown at the time the lift system is being designed, and therefore assessing the potential impact on demand is difficult. It is suggested that in the absence of any more detailed amenity brief, a figure of 5% of the served population should be considered as travelling to and from each of the amenity floor(s) rather than the main lobby level (so called entrance bias). This demand pattern should be considered as coincident with the main morning and lunchtime peaks and modelled in an overlaid fashion to simulate the actual predicted movement of the lifts in response to the prevailing demand. A check should be done to ensure that the generated demand in people / hour is broadly aligned with the area of amenity and the likely population it can safely accommodate, i.e. if the design population limit of an amenity (and this is usually defined by the fire strategy) is 500 people, and the 5% entrance bias is generating 250 people in the lunchtime peak hour, the 5% entrance bias is probably too small and a 10% bias should be tested; if the 5% bias is generating say 450-550 people it is likely to be appropriate.

This approach too however has challenges, not least of which is what demand profile should be modelled as representative of a typical day or week, and how might this profile vary between a front-of-house passenger lift vs. a goods lift, vs. a firefighters lift (all of which form part of the energy model).

Proposing a suitable demand profile for goods lifts is harder as we do not yet have established demand data for such equipment. In the absence of more detailed demand data a constant traffic profile is proposed with demand to and from each floor proportional to the predicted population at the floor. For goods lifts there is likely to be a higher demand in the evenings as the building is cleared of the day's waste, and in the mornings dealing with deliveries. The reader's attention is drawn to a 2018 paper on goods lift demand [9] which provides further guidance on quantifying demand for goods lifts. Separate dedicated firefighters lifts are likely to have very modest demand with only occasional use; they should however be modelled. Amenity demand should be modelled as per the comments above on passenger lifts.

4 CONCLUSIONS & RECOMMENDATIONS

Buildings and the systems within them consume a significant amount of energy and are worthy of rigorous analyses and design development to reduce their WLC footprint. Predicting the energy footprint of lifts is complicated and currently founded on many assumptions and derived information. It would seem a challenge currently to accurately predict a lift's WLC, let alone be able to compare robustly solutions from different suppliers and select the lowest WLC offer.

The interpretation of EPD embodied carbon data is particularly complex and nuanced and needs careful interpretation by experienced practitioners, especially where comparisons are being drawn between two or more lift systems. The EPD process would be greatly assisted if the lift industry could further develop its EPD data and adopt a scalable approach that would allow a representative EPD for say a 1000 kg lift at 1.0 m/s over five stops to be scaled up to accurately represent say a 1600 kg lift at 1.6 m/s over 10 floors. At present energy modelers are forced to select EPD data for the closest lift configuration to that proposed, and this is often a very blunt approach.

Operational energy assessment has an established methodology in ISO 25745-2, however a complementary simulation approach should be developed to further enhance the modelling and represent more complex lift systems and demand profiles. Demand models for ancillary lifts such as goods lifts and firefighters lifts need to be developed and adopted in a consistent fashion. The modelling approach might then also allow the development of energy optimized algorithms in preference to performance optimized algorithms, and the ability to compare the relative benefits of different systems.

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BIOGRAPHICAL DETAILS

Adam J Scott BEng (Hons) CEng FCIBSE MIMechE

Adam started his career in the lift industry 31 years ago with Otis in London, UK. After twelve years working across construction, service, modernization, and new equipment sales, he moved into the world of consultancy with Sweco (formerly Grontmij / Roger Preston & Partners) and has subsequently worked on the design of vertical transportation systems for many landmark buildings around the world.

Adam is the current Chairman of the CIBSE Lifts Group and of the CIBSE Guide D Executive Committee. He is the current codes and standards representative for the CIBSE Lifts Groups and sits on the British Standards Institute MHE4 technical committee. He is also a member of the BCO 2019 vertical transportation technical peer review committee. Adam is currently also the UK nominated expert for WG7 dealing with the accessibility standard EN81-70.