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E4
Energy Efficient Elevators and Escalators

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1 Introduction

Means of vertical transportation, for both people and other loads, have been employed by mankind since ancient times.

In early agricultural societies, these devices relied on men, animal or water power to lift the load. Rudimentary rope and pulley arrangements were used to support and move the required weight. Reference to this type of equipment can be found as far back as Ancient Greece.

The Industrial Revolution brought with it a number of technological advancements. Machine power allowed for fast developments and safety systems were introduced. In 1880, the first electric motor was used to power a lift.

Led by ever growing needs in the industry, with the necessity of moving great amounts of raw materials, and the introduction of steel beam construction and increasingly taller buildings, lift technology evolved rapidly.

Energy efficiency has not been a major market and technological driver in this sector. Other design options like space restrictions, reliability and safety, riding comfort, etc. have been the central concerns of the vast majority of manufacturers. The last few years have witnessed a change of course with companies introducing energy efficient technologies for competitive reasons and, at the same time, to help their customers save energy and money.

Taking into account demographic trends as well as a growing need for convenience, it is expected that the number of lifts and escalators will be rising worldwide, as well as in Europe. Further urbanisation in developing countries and a growing awareness of accessibility issues due to an aging population in Europe will foster the need for more of this equipment.

There is already about 4,8 million lifts, as well as about 75 thousand escalators and moving walks installed in the EU-27. Their energy consumption adds up to 3 to 5 % of the overall consumption of a building. About one third of the final energy consumption in the European Community occurs in the tertiary and residential sector, mostly in buildings. Due to the increasing comfort requirements, energy consumption in buildings recently experienced a significant raise, being one of the leading reasons for a growing amount of CO2 emissions. High untapped saving potentials exist with respect to energy-efficient equipment, investment decisions and behavioural approaches, in these sectors. The E4-project is targeted at the improvement of the energy performance of lifts and escalators in tertiary sector buildings and in multi-family residential buildings. As part of the project four major tasks were carried out.

a) A survey was conducted with the collaboration of national lift and escalator manufacturers and installers associations. The purpose of the survey was to overcome the lack of information related to the lifts and escalators installed base. Detailed data was collected regarding the technical characteristics of the equipment used (technology used, load, speed, motor power), as well as other relevant parameters, such as age of the installations, type of building and number of trips per year. This information was later used to estimate the energy consumption of lifts and escalators.
b) A monitoring campaign was carried out within the E4 project as a contribution to the understanding of energy consumption and energy efficiency of lifts and escalators in Europe. The aim of this campaign is to broaden the empirical base on the energy consumption of lifts and escalators, to provide publicly available monitoring data and to find hints on system configurations using little energy. Originally, 50 installations were planned to be monitored within the project. In the end, 74 lifts and 7 escalators, i.e. a total of 81 installations, were analysed in the four countries under study: Germany, Italy, Poland, and Portugal.

The monitoring campaign focused on a number of selected buildings of the residential and tertiary sectors (hospitals, hotels, shopping centres, private and public office buildings, residential buildings, etc.), taking into consideration typical lifts systems in use.

To ensure the repeatability of the measurements throughout the campaign, a methodology was developed for the measurement of the energy consumption of the lifts and escalators audited.

c) A technological assessment was carried out aiming at the characterisation of the existing technologies and, mainly, at emerging energy efficient solutions which can provide savings both in standby and running energy consumption of lifts and escalators. Technological solutions at component level are evaluated and this information was used to provide a credible base line for the evaluation of potential energy savings in combination with the results from the market survey and the monitoring campaign.

d) Lastly, an analysis based on existing literature as well as a study including interviews and group discussions with relevant stakeholders were made aiming at the identification of influential barriers to energy efficiency in the European lift and escalator market. Strategies and measures are outlined to overcome the barriers identified. An overview of technological and organisational features that increase energy efficiency in new and retrofitted lift and escalator installations is made, providing guidelines to help various stakeholders directly or indirectly concerned with lifts and escalators reflect and decide on measures to increase energy efficiency for existing and new installations.

This publication is aimed at presenting the main results of the project. In this report the word lift is used, although in other parts of the World the word elevator is more common to name the same type of equipment.
Chapter 2  Lift and Escalator Technologies

This section intends to provide an overview of typical lift and escalator technologies.

Lift systems have generally been individually engineered for each application. Each of its components contributes differently to the overall efficiency of the lift.

All lifts have common elements, independently of their working principle, including: cars (also called a "cage" or "cab"), doors, lights, ventilation, a motor and a control device. The car travels within an enclosed space called the shaft or hoistway.

There are two main classes of lifts: hydraulic and traction lifts. Traction lifts can be further subdivided into two categories: geared and gearless.

Figure 2-1 shows the typical range of rises for different lift technologies used today.

![Diagram showing typical rises for different lift technologies]

Note: MRL – Machine Roomless; MR – with Machine Room

Figure 2-1. Typical rises for currently used lift technologies

2.1 Traction Lifts

Electric traction lifts can nowadays be used in almost all applications without any considerable limitations regarding travel height, speed or load. A wide range of speeds is available – from 0.25 m/s to 17 m/s – and also of loads – some goods lifts can have rated loads in excess of 10,000 kg although normally at very low speeds.
In traction lifts, the car is suspended by ropes wrapped around a sheave that is driven by an electric motor. The weight of the car is usually balanced by a counterweight that equals the mass of the car plus 45% to 50% of the rated load. The purpose of the counterweight is to make sure a sufficient tension is maintained in the suspension system so as to ensure adequate traction is developed between ropes/belts and drive sheave. In addition, it maintains a near constant potential energy level in the system as a whole, heavily reducing energy consumption.

Traditionally, electric traction lifts were equipped with DC motors due to their easy controllability, but the development of variable frequency drives led to the introduction of the now prevalent AC induction motors or permanent magnet DC motors. These drives provide excellent ride conditions, with smooth acceleration and deceleration and high levelling accuracy.

There are two main types of traction lifts: geared and gearless. Geared lifts use a reduction gear to reduce the speed of the car while in gearless lifts the sheave is directly coupled to the motor.

**Figure 2-2. Simplified representation of a typical conventional traction lift installation** (source: Fraunhofer ISI)
2.1.1 Geared Lifts
Geared lifts are typically used in mid-rise applications (7 to 20 floors) where high speed is not a major concern (typical speeds range from 0.1 m/s to 2.5 m/s). The reduction gear allows the use of smaller, less expensive motors that can thus work at higher speeds, producing the desired torque.

The machine typically consists of the motor, brake, gearbox and traction sheave. The most commonly used reduction gear is still of the worm type, comprising a worm and a worm wheel. The reduction ratio of the gear is given by dividing the number of teeth on the wheel by the number of starts on the worm. These worm gears are relatively inefficient and are, in some few cases, being replaced by helical gears.

2.1.2 Gearless Lifts
In Gearless lifts, the sheave is driven directly by the motor, thus eliminating losses in the gear train. This type of lift has normally been used in high rise applications with nominal speeds between 2.5 m/s and 10 m/s. However, recent developments have made it available for use in low rise buildings and for speeds lower than 2.5 m/s.

The machine in gearless lifts consists of a motor, traction sheave and brake. Since the motor is directly coupled to the traction sheave, there are no transmission losses and they both rotate at the same speed. The motor must, therefore, rotate at a very low speed – the rope speed is equal to the circumference of the sheave multiplied by the rotational speed of the motor. For example, for a rated speed of 5 m/s and a sheave diameter of 750 mm the required motor speed is of only 128 rpm.

2.1.3 Machine Roomless Lifts
Saving highly valued construction space has always been a concern for lift designers and it has been the driver of highly innovative technological solutions. Conventionally, all lifts, either
traction or hydraulic, required a machine room where the motor – and pump, in the case of hydraulic lifts – and a control cabinet were stored (see figures 2-3 and 2-4) due to the size of the equipment. This machine room was typically located above the lift shaft for traction lifts (or below for hydraulic lifts).

Evolution in permanent magnet motor technology (see p. 23) and motor drives (see p. 17) allowed a significant reduction in the size and shape of these components which, in turn, made it possible to fit all the equipment directly into the lift shaft (these lifts are normally equipped with high efficiency gearless permanent magnet motors).

Also, the size of the motor is reduced by the roping system used (see pp. 33). The ends of the cables are fixed to the supporting structure, and suspension sheaves are provided above (or below) the car and counterweight creating a force-multiplying, compound pulley system.

With 2:1 or 4:1 roping, car speed is reduced to 1/2 or 1/4, respectively, of the rope speed, and the load on the rope is reduced to 1/2 or 1/4 as well, hence the diameter and number of ropes can be reduced and a smaller motor can be used.

Figure 2-5 shows the typical configuration of a Machine Roomless lift with 2:1 roping arrangement.

![Figure 2-5. Machine Roomless Lift typical configuration (source: Wittur)](image)
Some manufacturers have gone even further, presenting solutions with 10:1 roping systems, avoiding the need for a counterweight and, therefore, freeing up space for a larger car. This product is directed at renovations since it is able to substitute older and more confined cars with bigger ones that can better accommodate wheelchairs or baby carriers, for example.

Machine roomless (MRL) lifts were initially limited by factors such as travel height, speed and capacity, but nowadays they can be provided with travel distances of up to 80 m, capacities of eight (630 kg) to 21 people (1.600 kg), and contract speeds of up to 2,5 m/s.

Another advantage of MRL lifts is that the high efficiencies of modern traction gearless machines used rarely require additional ventilation.

MRL lifts offer alternative solutions without the limitations on speed and rise that may apply to a hydraulic installation and at competitive prices. Their market share is growing rapidly and is expected to make up 90 percent of new lift deliveries by 2020 [1].

2.2 Hydraulic Lifts
Hydraulic lifts are by far the most common type of lift installed in low rise applications (up to 6 or 7 floors). One of the main reasons for its wide acceptance in some European countries is its relatively low initial cost.

This type of lift uses a hydraulic cylinder to move the car. An electric motor drives a pump which forces a fluid into the cylinder. Valves control the fluid flow for a gentle descent, allowing the hydraulic fluid (usually oil) to flow back to the tank.

In some cases, the cylinder is placed in a hole in the ground. Some types of holeless hydraulic lifts can be found in the market for low-rise applications, which substantially reduce the risk of groundwater contamination. Due to restrictive laws in European countries, hydraulic lifts are usually of the telescopic cylinder or roped types.
Figure 2-7. Simplified representation of a typical conventional hydraulic lift installation (source: Fraunhofer ISI)

Since hydraulic lifts typically do not have a counterweight, conventional hydraulic lifts are the most inefficient, sometimes consuming three times more electricity than traction lifts [2]. Energy is dissipated as heat as the car travels down.

Hydraulic lifts travel at low speeds, typically below 1 m/s. The maximum travel distance for this type of lifts is around 20 m. This is due to the fact that as travel height increases, larger diameter pistons have to be used to resist the larger buckling forces. This increases the costs of equipment which makes the use hydraulic lifts less attractive when there are better alternatives [3].

Besides low initial cost, hydraulic lifts present some advantages over traction lifts, namely:

- Installation is very simple and fast.
- Space occupied by equipment, such as controls, motor, and pump is little and, therefore, the overhead machine room becomes unnecessary. These parts are normally located in low-cost areas of the building such as basements or below stairs.
• Conventional hydraulic units do not have counterweights which allows for narrower shafts. The absence of counterweights also diminishes the load on the building’s structure.

• The load is transferred to the ground and not to the building’s structure which translates into lower construction requirements and costs.

• Emergency procedures in hydraulic lifts are relatively simple. The car can be lowered by means of a manually operated emergency valve. Likewise, a hand pump can be used to lift the car in the event of power failure or control equipment failure.

Some of the disadvantages of conventional hydraulic lifts are:

• High energy consumption since the entire weight of the car must be lifted.

• High demand on the power supply when moving up

• Limited rise, speed of operation and number of starts per hour.

• Because oil viscosity changes with temperature, oil cooling or heating is sometimes required to maintain ride quality and performance.
2.3 Escalators and moving walks

Escalators are load carrying units designed to transport people, between two landings. They are driven by an electric motor and a drive system that moves steps and handrails at synchronised speeds. The escalator is supported by a truss which contains all the mechanical components, such as the drive unit, brakes and chain.

Escalators typically travel at speeds of around 0.5 m/s – fast enough to provide rapid displacement while not disregarding comfort and safety. They are used both in commercial buildings and in public transport facilities such as airports, metros and railway stations. For the transport of trolleys between two floors, inclined moving walks are used. At airports, horizontal moving walks are installed to move passengers more quickly to their destination.

Figure 2-8. Typical moving walk configuration (source: Schindler)

2.4 References


3 Emerging lift and escalator technologies

As already mentioned, technologic development in the lift industry has been mainly driven by factors other than energy efficiency. Safety, travel speed, acoustic noise, ride comfort and occupied space are, traditionally, the main concerns in lift design.

However, the demand for energy efficient products and greener buildings has grown, in the last few years, and the lift industry responded accordingly, presenting its customers with solutions that meet these growing demands.

Rising electricity prices have also been a major contribution to the demand for more energy efficient solutions. In some applications, electricity costs amount to many times the initial cost of the equipment and, therefore, investing in an energy efficient lift is often cost-effective in high traffic applications.

Energy efficient technological developments take different approaches that tackle different causes for inefficiencies in vertical transportation systems. These causes can be divided into two major groups: direct and indirect. Direct causes are the ones that can be directly related to the equipment. The most common direct losses are:

- Friction losses;
- Transmission losses;
- Motor losses;
- Brake losses
- Lighting losses
- Controller losses

Indirect causes are related to the operation of the equipment and are associated with user behaviour or traffic management options.

In this section, a brief description of energy efficient technologies applied to lifts is made.

3.1 Premium Efficiency Induction Motors

In the past, brushed DC motors were the technology of choice for lifts because they are easy to control, providing the best ride quality and an accurate levelling.

Due to increasing stringent regulations worldwide, induction motors have been subject to major efficiency improvements in the last decades.

Induction motors have a lower cost, are more robust and require much less maintenance than DC motors.
High efficiency motors are typically constructed with superior magnetic materials, larger magnetic circuits with thinner laminations, larger copper/aluminium cross-section in the stator and rotor windings, tighter tolerances, better quality control and optimised design. These motors, therefore, have lower losses and improved efficiency. Because of lower losses, the operating temperature can be lower, leading to improved reliability [1].

Some of the options to increase induction motors efficiency are presented in Figure 3-1.

![Figure 3-1. Options to increase the efficiency of induction motors](image)

Stator losses can be reduced by increasing the cross-section of stator windings which lowers their electrical resistance reducing $I^2R$ losses. This modification is where the largest gains in efficiency are achieved. High efficiency motors typically contain about 20% more copper than standard efficiency models of equivalent size and rating.

Increasing the cross-section of the rotor conductors (conductor bars and end-plates) and/or increasing their conductivity (e.g. using copper instead of aluminium), and to a lesser extent by increasing the total flux across the air gap between rotor and stator reduces the rotor losses.

Magnetic core losses occur in the steel laminations of the stator and rotor and are mainly due to hysteresis effects and to induced eddy currents. Both types of losses approximately increase with the square of the magnetic flux density. Lengthening the lamination stack, which reduces the flux density within the stack, therefore reduces core losses. These losses can be further reduced through the use of magnetic steel with better magnetic properties (e.g. higher permeability and higher resistivity) in the laminations. Another means to reduce the eddy currents magnetic core losses is to reduce the laminations' thickness. Eddy current losses can also be reduced by ensuring an adequate insulation between laminations, thus minimising the flow of current (and $I^2R$ losses) through the stack.
The induction motor efficiency also varies with the load. Motor efficiency drops sharply below 50% load due to the constant load losses (mechanical and magnetic losses show little change with the load). Figure 3-2 shows the effect of load on the efficiency of induction motors. Typically, the maximum efficiency is obtained in the range 60-100% of motor load, although the maximum efficiency operating point is dependent upon the motor design. It can clearly be seen that the efficiency drops sharply for very light loads.

![Motor Efficiency vs. Motor Load for IMs](source: ISR-UC)

Another effect of light loads on induction motors is the reduction of the power factor. The current in an induction motor has two components: active and reactive. The power factor is the ratio of active to total current. The active component is responsible for the torque and work performed by the motor (the active current is small at no load and rises as the load grows). The reactive component creates the magnetic field and is almost constant from no load to full load. A high power factor is desirable because it implies a low reactive power component. On the other hand, a low power factor means lower efficiency and higher losses.
Induction motor efficiency can be classified in accordance with IEC Standard 60034-30 [3], as shown in Figure 3-4.

Figure 3-4. Efficiency levels in the proposed IEC 60034-30 for 4 poled motors [1][3]

### 3.2 Linear Motors

The working principal of a Linear Induction Motor (LIM) is very similar to that of a normal Induction Motor. In a LIM the stator (primary) and the rotor (secondary) are flattened out and, therefore, instead of producing torque they produce a linear force. If Permanent Magnets are used in the rotor it becomes a Linear Synchronous Motor.
Linear Motors main applications are transport systems such as trains (e.g. Maglev), but it has never been used for a major lift installation in Europe. However, the idea of using it in lifts dates as far back as 1971, when a German company by the name of “Firma Kleemann’s Vereinigte Fabriken” patented a counterweight with an integrated linear motor. The first prototype was developed by Otis Lift Co. and was launched in 1992. It featured a tubular LIM in which the secondary windings are mounted in the counterweight’s frame, thus eliminating the machine room. The stator is a vertical column as long as the hoistway. The rope travels over an idler sheave at the top of the shaft. Figure 3-5 shows a typical LIM lift design.

![Figure 3-5. Linear Induction Motor lift](image)

One important property of Linear Motors is that the individual stator segments operate with low-duty cycle, so it is possible to get a much higher thrust than one might infer by scaling the force capabilities of rotary motors. The ability to overload a LSM without affecting its reliability is probably the single most important fact that makes these motors practical for lifts [5]. This makes Linear Motors a practical cost effective solution for high-speed (>10 m/s) installations.
If the linear motor is mounted on the car itself, then the counterweight can be eliminated, and the system becomes ropeless. This allows for designs that use horizontal switching between adjacent hoistways and for multiple cars to travel independently along the same shaft which leads to almost unlimited control options.

The main limitation to the use of Linear Motors for lift propulsion are the production costs associated with the large motor length, but they are expected to decrease as the technology matures.

Linear Motor technology is not expected to reach its full potential in the next few years, but the technology is clearly worthy of serious consideration for future designs.

This technology has also been used to operate lift doors, reducing moving parts and maintenance issues significantly. Door problems account for around 40% of all service calls [6].

3.3 Advanced Drives and Regeneration

The choice of the drive has historically been motivated by factors such as travel speed, levelling accuracy and comfort. Before the introduction of solid-state control techniques, the most common option was the Ward Leonard set which provided the best ride quality. However, there are large energy losses in the motor and generator arrangement, which converts electrical energy into mechanical energy and finally back to electrical energy again.

The advent of power semiconductors and subsequent evolution of AC motor control techniques has led to its wide spread use with equivalent ride quality and even some advantages such as lower maintenance, faster response, energy savings, lower peak demand and better power factor.

The most common types of motor drives in use today are:

- DC motor with Ward Leonard set
- DC motor with solid state controller
- Two-speed AC motor
- AC induction motor with Variable Voltage controller
- AC induction motor with Variable Voltage Variable Frequency controller
- AC Permanent Magnet Synchronous Motor with Variable Voltage Variable Frequency controller

A detailed description of these drive systems can be found in [4].

In DC systems, solid state controllers have been the most common option since the early 90’s, substituting the Ward Leonard set with great efficiency improvements and more accurate speed and levelling control. The energy costs when using solid state controllers can be reduced by as much as 60% when compared with equivalent Ward Leonard drives [4].
Although DC motor controllers are simple and inexpensive, DC motors require frequent maintenance because of the brushes. In order to reduce maintenance costs the market begun shifting towards AC induction motors. The evolution of control techniques for induction motors has led to very reliable and accurate systems.

In AC motors, the speed is determined by the number of pole pairs and the frequency of the supplied current. Initially, pole-changing motors were used to achieve the lift’s two operating speeds. However, a large flywheel has to be used to smooth the sudden change in torque, thus reducing the jerk perception of passengers. The flywheel stores energy which is dissipated later, contributing to the low efficiency of these systems. The use of two-speed motors presents some problems regarding levelling accuracy and ride comfort.

Variable voltage controllers were widely installed from the mid-eighties to the early nineties. These systems are very simple. They rely on three pairs of back-to-back thyristors for varying the RMS (root mean square) voltage to the motor and, as a result of this voltage reduction, there is an increase in motor slip, which translates into speed reduction. However, the increase in motor slip also translates into a large increase in the motor losses.

Furthermore, at low voltages, the firing angles of the thyristors are large and the harmonic content of the voltage becomes very high. As a result, the motor gets hot and the system efficiency drops. The efficiency of variable voltage systems is very low.

Today, the most widely used drive system is the Variable Voltage Variable Frequency (VVVF) drive. It relies on the fundamental principle that the speed of an induction motor is directly linked with the supply frequency applied to the stator windings. By varying the frequency and by keeping the voltage / frequency ratio constant, the speed-torque curve is moved, maintaining a constant pull-out torque and the same slope of the linear operation region of the curve (Figure 3-6).

![Figure 3-6. Speed-Torque Curves for an Induction Motor (f_1 < f_2 < f_3 < f_4 < f_5 and f_5 = 50 Hz) (source: ISR-UC)](image)

Figure 3-7 shows the general configuration of a VVVF drive. The three-phase, 50 Hz alternated current supply is initially converted into direct current, then filtered and finally the inverter converts the DC voltage into the desired voltage and frequency output applied to the motor.
The most widely used VVVF drive is the PWM (Pulse Width Modulation) voltage source inverter. The inverter switches are used to divide the quasi-sinusoidal output waveform into a series of narrow voltage pulses and modulate the width of the pulses (Figure 3-8). The PWM inverter maintains a nearly constant DC link voltage, combining both voltage control and frequency control within the inverter itself. The objective of the sinusoidal PWM is to synthesise the motor currents as near to a sinusoid as economically possible. The lower voltage harmonics can be greatly attenuated, and therefore the motor tends to rotate more smoothly at low speed, maintaining ride comfort at high levels. Higher order harmonic motor currents are limited by the motor inductance. Torque pulsations are virtually eliminated and the extra motor losses caused by the inverter are substantially reduced. Other advantages include a near unity power factor throughout the speed range, low distortion of the motor current and, with proper topology, regeneration capability.

Some modern VVVF drives now use a sophisticated control method designated Vector Control. The objective of Vector Control is to give independent control of torque and flux in an AC machine. In most types of VSDs, while keeping V/f constant, the flux is only held approximately constant and under dynamic conditions this provides limited control strategy performance.

When combined with encoder feedback to measure slip, full motor torque becomes available even at very low speeds, including zero rpm.
For this type of control it is necessary to use the dynamic model equations of the induction motor, based on the instantaneous currents and voltages, in order to control the interaction between the rotor and the stator, resulting in the flux and torque control.

The attention of researchers has turned towards simplification, as well as the refinement of these quite sophisticated control methods. One issue was the desire to avoid the mechanical speed/position sensor needed with many of these control schemes. Electrical measurements are usually acceptable since the sensors can be placed anywhere, preferably inside the inverter cabinet, but a mechanical sensor is often undesirable because of space restriction or the added cost and complexity. Such arguments have particular weight with smaller motors. Of course, a certain loss of accuracy and dynamic response may be unavoidable when the speed sensor is omitted.

Another important aspect is the acceleration process. As it can be seen in Figure 3-10, if the motor is simply turned on (situation (a)), without any speed control, the rotor losses will be higher than with a pole changeable motor (situation (b)). A more efficient acceleration technique uses a VSD (situation (c)), that will significantly reduce energy consumption, comparatively to the other mentioned techniques.
Potential energy is constantly being transferred while the car is moving. If, for example, a lift is travelling down full (or up empty) the motor is actually being driven by the load and preventing the car from falling. Typically, the generated (braking) power in the motor is dissipated in a resistance, returned to the main supply naturally, if the motor, acting as a generator, is directly connected to the grid or, depending on the topology, some VVF drives also allow the braking energy to be injected back to the power network.

In some countries there are restrictions on the injection of power into the distribution network. Even in these cases, regenerative braking should not pose a problem, since the total load of the building (computers, servers, lighting, HVAC) will be higher than the peak power injected by a lift.

![Figure 3-11. Topology of a VSD-PWM with dissipation resistance (Rd) (source: ISR-UC)](image1)

![Figure 3-12. Topology of a VSI-PWM with regenerative capacity and power factor control (source: ISR-UC)](image2)

When the lift is going down, and the load weight (people inside) is larger than the counterweight, then the motor torque is in opposite direction to the speed, i.e., the motor is braking. In the same way, when the lift is going up unloaded, energy savings can be reached if the motor is controlled with a regenerative VVF drive.

Theoretically, if there were no losses, the regenerated energy would be equal to the motoring energy. However, there are still losses due to the existence of friction losses (e.g. friction in the guide rails, air resistance), motor losses (e.g. the copper losses, the iron losses and the friction and windage losses) and, in geared systems, losses in the gearbox (this is especially significant in systems equipped with worm gears where the efficiency in the reverse direction is considerably lower than in the forward direction).

Because it adds a significant cost to the installation, regeneration is not always cost-effective, especially with reduced traffic in low- and mid-rise buildings.
In most cases, providing there is other equipment connected to the supply (e.g. lighting and heating) available to consume any regenerated power from the lift – which is true for most buildings – no special meter is needed to record the reverse power. Instead, regenerative systems transmit the power back to the distribution transformer and feed the electrical network in the building along with power from the power supply.

Figure 3-14 illustrates the functioning of a lift equipped with a regenerative drive.
Figure 3-14. Regenerative operation of a lift equipped with a regenerative inverter (source: Mitsubishi)

In Figure 3-15, possible energy savings in lifts, using different technologies, can be seen. The use of a regenerative gearless VVVF drive can reduce the consumed energy to 19%, when compared to a conventional system, using a pole changing drive (two-speed induction motor).

![Energy balance of lifts, Average energy consumption, percentage](source: Flender-ATB-Loher, Systemtechnik).

3.4 Permanent Magnet Motors

Permanent Magnet Synchronous Motors (PMSM) are rapidly becoming the leading motor technology within the lift market in Europe. It presents many advantages, such as a simplified mechanical system for the lift, improved comfort, reduced noise and vibration, and energy savings.
Since these motors do not have windings in the rotor – instead, the magnetic field is provided by the magnets – they have less Joule losses than induction motors and the magnetic losses in the rotor are also much reduced.

Traditionally, ferrite magnets were used to provide the magnetic field in PMSM, but, as the technology advances and its costs decrease, rare earth alloy magnets are gaining ground. These alloy materials have high magnetic energy density improving the power-to-weight and torque-to-weight ratios. Samarium Cobalt (SmCo), and Neodymium, Ferrite and Boron (NdFeB) are some examples of rare earth alloy magnets used in high performance motors.

![Magnet Energy Product vs. Time](image)

**Figure 3-16. Advances in magnet energy product [7]**

Special care must be taken to insure that the working temperature of the motor respects the temperature upper limits of the permanent magnets and demagnetisation is avoided.

The use of permanent-magnets allows for a multipole arrangement, and the result is a more compact, higher efficiency high torque / low speed machine ideal for gearless lift applications. For the conventional induction machine, there are limitations on compactness because the power factor and efficiency rapidly decrease as the number of poles increases [8]. Because it no longer requires an exciting current, PM motors have higher efficiency and present faster response speeds when compared to conventional induction motors. Furthermore, these motors maintain their high efficiency regardless of the number of poles. When supplied from a Pulse Width Modulation Variable Voltage, Variable Frequency inverter, the power factor is maintained near one.

The compactness of PMSMs and the use of direct drive coupling allowed the elimination of the Machine Room, above or adjacent to the hoistway. The motor and control systems could be mounted within the hoistway itself, instead of placing them in a separate room. The absence of a Machine Room leads to lower construction costs and frees highly valuable space normally
occupied by lift support systems. Also, lift machine rooms can be areas where substantial air leakage and heat loss from the building occurs.

The first idea, triggered by the Linear Induction Motor lift by Otis, was to place the motor in the counterweight. This idea was soon abandoned. The motor would not be easy to reach if something went wrong, and had to be fed by a travelling cable going to the counterweight. The motor is now commonly located at the top of the shaft. To service the lift, the car is stopped just below the motor and controls and a temporary machine room is created.

Some manufacturers use axial flux motors, a very compact, light, and as thin as possible motor which can be wall mounted within the reduced room available in the hoistway. These motors, first introduced by KONE, are very similar in operation to the more common radial flux designs. The stator produces a variable speed rotating magnetic field to which the rotor aligns itself at synchronous speed. Permanent magnets are affixed to a disc shaped rotor, whereas the stator has a three-phase toroidal winding. The sheave is integrated in the rotor to achieve greater compactness.

Figure 3-17. Disc Permanent magnet synchronous motor (source: KONE)

This design has been expanded to higher power applications. Increasing the disk-shaped motor further would have led to impractical diameters while the axial force caused by the permanent magnets would have increased dramatically, requiring large and expensive bearings. The solution was found with the application of the dual rotor concept. The stator diameter dimensions fitted nicely, while the magnet forces of the two rotor parts balanced each other [9].
Other manufacturers decided to keep the radial flux design while taking advantage of multipole design and permanent magnets to achieve a very slim and compact machine.

Instead of disposing the traction machine elements (sheave, brake, motor, and encoder) along a straight line, which limited its possible reduction in length, in the slim traction machine, developed by Mitsubishi, these elements are disposed radially.

The drive sheave is integrated with the rotor which has been given a hollow cylindrical form, allowing the inner surface to be used for an internal expanding double brake. The encoder has been installed within the space inside the brake mechanism [10].

A comparative scheme of a conventional and slim traction machine is shown in Figure 3-18.

![Comparative scheme of conventional and slim traction machine](source: Mitsubishi)

**Figure 3-18. Mitsubishi’s Slim traction machine PMSM**

Even with larger sized PMSM machines for high-rise / high-speed applications that can no longer fit within the hoistway, the machine room size can be drastically reduced. The overhead machine room no longer has to extend beyond the size of the hoistway. Another option is to place the traction machine and controls in a very small side machine room as show in Figure 3-19.
Even though the present asynchronous VVVF gearless technology is very energy efficient, the motor and drive efficiencies are usually less than 90%, for lower powers. Figure 3-20 shows the much higher efficiency levels of PM motors when compared to induction motors fed by inverters.

Figure 3-20. Comparison of Inverter fed Induction and Permanent Magnet Motor efficiencies (source: Leroy - Somer)

The difference is even more noticeable as the speed decreases, as it can be seen in Figure 3-21.
Figure 3-21. Variation of motor efficiency with motor speed - PM motor vs. Induction motor (source: Leroy-Somer)

The Dual rotor permanent magnet motors can have efficiencies of up to 93%.

Figure 3-22. Dual Rotor PMSM (source: KONE)

3.5 Traffic Handling / Management

In the beginning, lifts were controlled by operators, in the car, who manually operated doors, moved and stopped the car at the desired landing. Early group control systems also relied on human dispatchers who directed lift traffic from the main landing.
After the introduction of relay logic automatic controls, in the 1950’s, human intervention was dispensed with. Soon lifts were being controlled electronically and, nowadays, programmable logic controllers (PLCs) and microprocessor based systems can be found in most applications. These controls assure that lifts are properly dispatched, that doors open and close at the right time, etc.

Lift controllers have two main objectives:

1) command the car to move up or down and to stop at the appropriate landings;

2) efficiently serve passengers demands and, in a lift group, coordinate the operation of the individual cars in order to make efficient use of the lift group.

In order to accomplish the first objective, values of speed, acceleration, and jerk are set based on a series of feedback signals that indicate the lift’s position within the shaft. These values are typically selected by the traffic design and ride quality requirements, but the lift’s energy consumption can also be greatly affected by its speed profile. An efficient operation is achieved by selecting optimum values of speed and acceleration for the movement between stops. For example, during lighter traffic periods, lift speed can be optimised to save energy whilst not compromising handling capacity. Other control systems are able to optimise the energy used for the next journey taking into account the car load, direction of travel, and travel distance.

Lifts can be installed as a single unit or as part of a group when a single unit is not able to adequately serve the building’s population. Where more than one lift is installed together, some method of interconnecting their control should be implemented to optimise their operation. In these systems, landing call buttons and signalling devices are common to all the cars which are, in turn, commanded by a group traffic control system. The function of the group control system is to efficiently assign landing calls to each individual car and, at the same time, distribute the passengers among the floors to which they wish to go.

The controller receives several inputs, such as landing and car calls¹, the cars’ position, direction of travel and load, and produces a number of outputs to operate the doors, motor drive and signalling devices. Generally, the more information the controller has, the better it will perform.

One important input is passenger demand, which varies during the day. Figure 3-23 shows a classic traffic pattern during the day in an office building. At the start of the day, there is usually a larger number of up-travelling traffic (up peak), as travellers arrive at the building. At the end of the day outgoing (down peak) traffic demand dominates. In the middle of the day, there are other, smaller, up- and down-peaks, as building occupants leave and arrive from

¹ A landing call occurs when a passenger at a floor pushes an upward or a downward button and waits for a car in order to move into other floors. A car call is generated when a passenger enters the car and presses a floor button in the lift.
lunch. Between these peak periods, during the morning and the afternoon, there is an interfloor traffic demand, which prevails during most of the working day.

Figure 3-23. Classical traffic demand pattern for an office building [11]

A number of traffic control algorithms have been developed that define the strategies undertaken in order to optimise the use of grouped lifts by, for example:

- minimising passenger’s waiting time
- minimising passenger’s journey time
- minimising the variance in passenger’s waiting time
- maximising the handling capacity
- minimising the energy consumption

Nowadays, traffic control systems rely on more than one algorithm or program to allocate lifts to landing calls, depending on the pattern and intensity of the traffic flow. For the selection of the appropriate algorithm, a traffic analyser assesses the prevailing traffic conditions. Modern traffic controllers can use artificial intelligence techniques – artificial neural networks, fuzzy logics and/or genetic algorithms – to enhance the service’s effectiveness.

The controller can perform even better if the destination of the passengers is known prior to them boarding the lift. With this purpose, hall call control systems were developed. These systems work by replacing the conventional up or down buttons near the lift doors with consoles located in the building’s lobby. Passengers enter their destination as they go in the building and are immediately dispatched to a lift servicing their destination. Passengers are thus grouped by destination, significantly reducing starts/stops and travel time. Since the controller has broader information on the variables at stake, it is able to make more intelligent decisions.
It is evident that the way lifts are controlled has a major impact on energy consumption. By efficiently delivering passengers with the least amount of trips, starts and stops, and number of lifts used, the energy consumed is significantly reduced. Also, less effective traffic controllers, causing longer waiting times, can lead to the improper use of the system by impatient passengers (e.g. pushing both up and down buttons), further degrading the quality of the service.

Provided passenger’s waiting times are kept within reasonable limits, the energy consumed should be minimised. A number of different strategies can be engaged to achieve this purpose:

- Shut down lifts during periods of low traffic demand

Lift groups are designed to respond optimally to heavy traffic demand situations, such as during up- or down-peak demand. During interfloor traffic, the capacity of the installation is never fully used. Therefore, it may make sense to disable some of the lifts in the installation during this low demand periods, without significantly affecting the system’s traffic handling performance. This would by itself produce considerable energy savings, but it has one side effect that further enhances the energy efficiency of the installation. By reducing the number of lifts in use, the car load is increased, moving closer to the counterbalancing ratio.

- Appropriate zoning arrangement

In high-rise buildings, it is possible to group the lifts to serve particular zones of floors. This creates the need for people travelling to floors within that zone to use the same lifts, thereby reducing the number of start / stop cycles made and avoiding unnecessary energy losses. Appropriate zoning arrangement will not only improve the energy performance of the lift installation, but it will also improve the handling capacity and the quality of the service due to a shorter Round Trip Time.

- Use of advanced algorithms

Employing advanced algorithms that track where each lift is located, to consider the potential energy available from its car and counterweight locations.

- Monitoring Devices

Modern controllers have logging capabilities which are indispensable for maintenance purposes. They register data related to failures, but can also provide additional data that can be used to improve the performance of the system. By logging information on the energy consumption of lifts a means of conducting energy audits is also provided. The availability of information improves the awareness of building owners/managers on the electricity consumed by the system. This information may also be combined with other information logged by the controller (e.g. traffic patterns, idle times, and load) and used to improve the energy performance of the installation.
• Hall Call allocation and Double-Deck lifts

The use of hall call allocation enables the system to assign the number of passengers that is more likely to match the counterbalancing ratio of the lift, thus minimising the energy used. This is especially pertinent in low traffic periods, when it is less important that lifts travel at their maximum capacity.

One solution to improve the traffic handling capabilities of a lift system in very high-rise buildings is to use Double-Deck (DD) lifts. This system consists of two individual cars that travel together, the upper one serving odd floors and the lower one even floors. Both cars travel using the same shaft and drive system, saving space and resources.

For DD lifts to work efficiently it is necessary to have a large floor area typically in excess of 2,000 m² to ensure a balanced demand and a high level of coincidence for people travelling to consecutive levels [12].
Modern double-deck systems use sophisticated controls to ensure that the best deck is allocated to calls minimizing waiting times, travel time and number of stops.

When combined with hall call control systems, double-deck lifts performance is further improved, allowing buildings to reach a lift performance that would be impracticable with single-deck lifts.

Recent developments in intelligent control and safety systems have allowed the use of two independent cars travelling in the same shaft. This can translate into a significant improvement in handling capacity (Figure 3-25). Manufacturers claim that by using such systems 40% more passengers are transported in a typical four-shaft group.

### 3.6 Transmission and Roping

The low and medium speed traction lift market (< 2.5 m/s) is still largely dominated by geared units. In these lifts, a gearbox is used to reduce the shaft speed and produce the required torque to start the lift car moving. Gearing allows the use of smaller, less expensive motors. However, energy is dissipated as heat caused by friction between the gear’s teeth, and churning losses in the lubricant.

**Figure 3-26. Worm gear**

Typically, worm gears have been the prevalent choice for the reduction of speed since they provide good shock absorption, quiet operation, and high resistance to reversed shaft rotation. However, their efficiency is relatively low (typically 60% - 70%) and the efficiency in reverse rotation is significantly lower than in the forward direction. The efficiency of the gear train depends on the lead angle of the gears and the coefficient of friction of the gear materials. The efficiency also depends on the operating parameters of the gear train. Usually, smaller reduction ratios, higher input speeds to the worm, and larger sizes result in higher efficiency.

Helical gears have higher efficiency than worm gears, typically over 98% per stage, and are being used in some of the more recent lift systems. Since there is less sliding between the gear’s teeth, they present improved efficiency.

According to information provided by manufacturers, the transmission efficiency of helical gears is roughly 20 - 30% higher than that of worm gear, thus enhancing the overall
mechanical efficiency of the lift equipment. However, helical gears can be noisier and have higher initial costs.

Figure 3-27. Helical gear

Planetary gears are also used by some of the equipment manufacturers to replace the low efficiency worm gears. They have the additional advantage, over helical gears, of occupying less space.

A variety of roping systems can be employed dependant on the particular conditions of each installation (e.g. machine positioning, rated load and speed, available space, etc.). Examples of commonly used roping systems are shown in Figure 3-28.

Figure 3-28. Commonly used roping systems (source: Mitsubishi)

<table>
<thead>
<tr>
<th>Diagram</th>
<th>Ratio</th>
<th>Wrap</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>1:1</td>
<td>Single wrap</td>
<td>Mid-, low-speed lifts</td>
</tr>
<tr>
<td>(b)</td>
<td>1:1</td>
<td>Double wrap</td>
<td>High-speed lifts</td>
</tr>
<tr>
<td>(c)</td>
<td>2:1</td>
<td>Double wrap</td>
<td>High-speed lifts</td>
</tr>
<tr>
<td>(d)</td>
<td>2:1</td>
<td>Single wrap</td>
<td>Freight lifts, Machine-room-less lifts</td>
</tr>
<tr>
<td>(e)</td>
<td>2:1</td>
<td>Single wrap</td>
<td>Machine-room-less lifts</td>
</tr>
</tbody>
</table>
In lifts that use 1:1 roping schemes, the car travels a distance equivalent to the perimeter of the sheave, for each revolution. In Europe, however, most of the lifts are roped 2:1, which means that the sheave must turn twice as much for the car to travel the same distance as in 1:1 roped lift. With the 2:1 roping scheme, however, the motor is only required to produce half of the torque of the 1:1 roping scheme. The 2:1 roping scheme, therefore, requires a smaller motor to generate the torque required to move the car and allows for the elimination of the gearbox.

Under ordinary conditions, it is assumed that the simpler the roping arrangement, the more efficient the system is. The smaller the number of pulleys required, the lower the losses will be. Therefore, it is more efficient to locate the traction sheave directly above or in the shaft than to divert the rope from the machine room into the hoistway using additional pulleys. Also, for pulleys, roller bearings should be given preference over friction bearings. Losses of around 10% are expected for each demultiplication wrap.

The internal frictional losses within the rope increase with thickness (thinner ropes have less losses) and decrease as the diameters of traction sheave and rope pulleys increase. In addition, rope lubrication should not be neglected.

The external frictional losses from the rope can also be reduced. Careful consideration should be given to the traction efforts in the sheave so that neither slippage nor excessive tractive force occurs.

The weight of the sheave and pulleys also has an effect on the energy consumption of lifts. As the speed increases, the traction sheave and rope pulleys also revolve faster so that they have an increasingly greater influence on the starting output. The diameters of the traction sheave and rope pulleys cannot be reduced indefinitely, but it is possible to use polyamide instead of cast iron for the rope pulleys, thus reducing the moment of inertia by a ratio of approximately 1:5 [13].

![Figure 3-29. Polyamide lift sheave.](image)

The decrease in the diameter of the sheave is also limited by the bending radius of the ropes. The use of advanced materials and innovative configurations in rope construction has led to a significant reduction of the sheave's size and the weight of the ropes.
The first step was taken with the introduction of aramid ropes in 2000. These aramid ropes are four times lighter than conventional steel ropes for the same breaking strength. The synthetic rope has higher fatigue strength under reverse bending stress than steel ropes, which allows bends to have a smaller radius. Furthermore, they do not require lubrication throughout their lifetime, which is an important ecological advantage, besides saving maintenance costs.

The weight of the ropes is becoming an increasingly important concern as building heights increase at a fast pace. Rope weight increases rather exponentially with height and can reach 50 to 70 tons to move just a few passengers in a high-rise building [14].

Figure 3-30. Cross section of the SchindlerAramid ropes (source: Schindler)

Aramid ropes are very costly and some manufacturers have now started to use traction belts instead of ropes. These belts consist of a band of ultra-thin steel cables encapsulated in a polyurethane sheath. These new belts are approximately 20% stronger, do not require maintenance lubrication, and can reach twice the life-time of the standard steel ropes.

Figure 3-31. Otis GEN2 polyurethane flat belt (source: Otis).

The higher bending capabilities of both aramid ropes and polyurethane belts make possible the use of a smaller traction sheave which results in a smaller torque requirement and the use of a smaller motor.
For example, flat belts allow the use of a 100 mm diameter sheave instead of the commonly used 720 mm diameter sheave. This way, at a given lift speed, the smaller sheave rotates 7.5 times as quickly as a 720 mm sheave, so a smaller motor can deliver more torque to the load. Furthermore, it avoids the use of a gearbox which results in supplementary energy savings.

**Previously: Steel cables**
Steel cables are relatively inelastic. They need a driving pulley diameter of at least 320 mm to handle the cable diameters required for elevators. The complete conventional motor including drive gears must be large enough to match. A system that requires space.

**New: Traction Belts**
Traction belts are flexible. They use a much smaller driving pulley diameter than steel cables, only 85 mm, requiring a much smaller motor: a design that saves space.

*Figure 3-32. Traction belts vs. Steel cables (source: Schindler)*
3.7 Other Lift loads (standby loads, doors, lights, fans for ventilation, safety devices, automatic controls, sensors, etc.)

Lifts consume energy even when they are not raising or lowering loads. This energy consumption can represent more than 90% of the total electricity consumption in lifts with a low number of daily trips and is attributable to equipment that is constantly working, such as control systems, lighting, ventilation, floor displays and operating consoles in each floor and inside the lift cabin.

In order to achieve energy savings in these loads, there are two possible approaches: to use equipment with better efficiency than the standard equipment used and to switch off such equipment when the lift is idle.

Lighting, in particular, is one of the loads that most contributes to the standby electricity consumption of lifts and therefore provides one opportunity that should not be missed, especially since very good off-the-shelf solutions are available.

Lift car lighting is usually provided either by incandescent or fluorescent lamps. Incandescent lighting is rapidly becoming an obsolete technology due to its low luminous efficacy (around 15 lm/W) and short lifetime. Fluorescent lamps, particularly Compact Fluorescent Lamps (CFLs) have been growing in importance over the last few years. They present a much better luminous efficacy (around 50 lm/w) and a longer lifetime, of around 6.000 hours. Linear Fluorescent lamps present an even better luminous efficacy that can reach 100 lm/W. Fluorescent lamps have the disadvantage of containing mercury, which constitutes an environmental concern.

LED lighting is a technology that has been subject to great improvements over the last few years, reaching now the 150 lm/W, and is expected to go even further. Although they are still expensive, when compared to other types of lamps, their price is likely to decrease due to economy of scale and is already offset by their very long lifetime that can reach 50.000 hours. Additionally, their lifetime is not reduced by frequent on/off cycles.

Table 3-1. Comparison of lamp’s major characteristics

<table>
<thead>
<tr>
<th>Type of Lamp</th>
<th>Lifetime (hours)</th>
<th>Luminous efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>750-2.000</td>
<td>10-18</td>
</tr>
<tr>
<td>Halogen incandescent</td>
<td>3.000-4.000</td>
<td>15-20</td>
</tr>
<tr>
<td>Compact fluorescent (CFL)</td>
<td>8.000-10.000</td>
<td>35-60</td>
</tr>
<tr>
<td>Linear fluorescent</td>
<td>20.000-30.000</td>
<td>50-100</td>
</tr>
<tr>
<td>High-Power White LED</td>
<td>35.000-50.000</td>
<td>30-150</td>
</tr>
</tbody>
</table>
LEDs are also a very efficient solution for displays which can be dimmed for even lower consumption, and can be cycled on-off without impacting their lifetime.

![Figure 3-33. Evolution of the Luminous Efficacy of different technologies](image)

Design options such as high-albedo interiors also help achieve a good lighting in the car.

Car ventilation also contributes to the energy consumption of the lift system. Electronically controlled permanent magnet motors (EC motors) can achieve very high efficiencies and competitive prices in variable speed applications. EC motors always require additional electronics, responsible for the commutation in the windings depending on the position of the rotor. To rotate the EC/BLDC motor, the stator windings should be energised in a sequence. It is therefore important to know the rotor position in order to understand which winding will be energised following the energising sequence. Rotor position is sensed using Hall Effect sensors embedded into either the stator or the rotor, but new sensorless designs are becoming available.

The development of motor technology combined with a global reduction in the cost of electronics and power electronics over the last few years have made it possible to achieve EC fan prices that are now broadly comparable to the costs of similar solutions involving the use of AC induction motors. The external rotor design also contributed to the competitive price of EC motors. They have a stator placed inside and the rotor placed outside, on which the impeller or fan blades can be mounted directly. Thus, the motor is placed in the airflow and benefits from this cooling effect. The design makes for a compact fan - motor unit.

Especially with fans, setting the operating point to meet the required flow has a noticeable impact on energy consumption, as the power consumed changes with the third power of speed. Good speed control is also an important factor in regard to acoustic noise and vibrations.
These motors can achieve efficiencies well above the 75% for small power fan-motors and above 85% for higher powers (above 1 kW).

Figure 3-34. Efficiency of EC/BLDC motors (source: EBM-Papst)

In addition to the use of efficient components, energy can be saved by switching off equipment, or putting it in a low energy mode, when not being used. As mentioned earlier, during low demand periods, shutting down completely one or more lifts within a group can also be a good energy saving option, without compromising the quality of the service.

One alternative is to have two distinct standby modes working in a sequence. The first one does not imply an addition to the passenger waiting time as only components that can be instantly turned on would be completely or partially disabled. Examples of such equipment are:

- Lighting
- Ventilation
- Car displays (directional arrows, floor indicator,...)
- Dimmable landing displays

The second standby mode shuts down further components, but the system may take a longer time to reboot due to the nature of the switched off equipment:

- Drive unit
- Door operators
• Car electronics
• Light curtains / door detectors

Due to the extension of the waiting times – the rebooting sequence can take up to 30 seconds – this second standby mode would only be suitable for long periods of low passenger demand.

Another cause for losses is that the lift shaft can facilitate thermal losses from the building.

Some lift shafts are required to have vents in order to dissipate smoke in case of fire, but also, in high-speed lifts, to reduce wind noise and transient pressure changes caused by the car movement. They also help dissipating excess heat from the lift motor. Through leaky or open basements, outside air flows into the shaft, is heated in the pit walls and rises - as a result of chimney effect. This flow also draws in warm air from the heated space opposite the lift doors, which leads to comfort problems (drafts). The heated air flows outwards through the air vents at the top of the shaft.

Correct insulation around the entire heated volume should be ensured to avoid such losses. The lift shaft and machine room should be well insulated and flaps in the air vents should also be airtight. Another option is to locate the lift shaft entirely on the outside of the heated volume, the lift doors leading to unheated spaces or to the outside (this solution is not always possible, for example in cold climate regions).

Another cause for inefficiencies are the guide rails and shoes that ensure travel in a uniform vertical direction. Correct maintenance (e.g. alignment, lubrication) should be guaranteed to minimise the losses in these components. Furthermore, when correctly maintained, the use of roller guides is preferred to the use of sliding guides. Tests show an effective coefficient of friction for roller guides of 0,03. With sliding guides, this friction can easily be 10 times as much, especially if the lubrication is not well maintained. Sliding guides can easily cause over 100 kg (1.000 N) of frictional losses in the system if it is not well balanced, or if the 4 guides and rails are not perfectly co-planar. Even with perfect balance, loads can be placed in the car off centre, causing frictional losses at the guides. In roller guides, unbalances can also cause flat spots, creating noise and reducing ride quality.
3.8 Efficient Hydraulic Lifts

In conventional hydraulic lifts, the electricity consumption, when the lift is moving, is much higher than in traction lifts. A number of factors contribute to their lower energy efficiency, namely:

- Losses in the pump.
- Losses in the valve unit due to pressure drop.
- The potential energy is dissipated as heat when travelling down.
- Absence of counterweight to balance the potential energy needed to lift the car.
- Since the oil pressure and flow to the cylinder are controlled by returning oil to the tank through a bypass valve, the pump works at constant flow, wasting energy especially during acceleration and deceleration.
- Because oil viscosity changes with temperature, oil cooling or heating is sometimes required to maintain ride quality and performance. Heating is sometimes necessary when the machine room is subject to low ambient temperatures (e.g. basements, below stairs) leading to an increase in oil viscosity. On the contrary, heavy duty situations lead to the dissipation of large amounts of heat into the oil and cooling may be necessary.

Hydraulic lifts only consume energy to lift the car. During downwards travel the car descends due to gravity and controlled oil flow. One simple way to reduce the energy consumption of hydraulic lifts is to adjust the travel speed without compromising the round-trip time, to make use of this characteristic. This is done by reducing the up travel speed and raising the down travel speed. This way a smaller motor can be used and energy consumption can be reduced by around 20% [15].

Another simple way to reduce the energy consumption is to reduce the weight of the car by using lighter materials.

Mechanical hydraulic valves, where the flow of oil is controlled by internal hydraulic feedback, have problems in compensating for variations in oil viscosity and pressure. Electronic sensing of the flow of oil using proportional solenoids fully compensates for these variations while providing better efficiency.

Nowadays, products that use VVVF drives to power the pump are becoming available. By varying the speed of the pump, only the amount of oil necessary to move the lift is supplied as opposed to conventional systems where the amount of oil pumped is constant and partially fed-back into the tank. Another advantage is that the starting current is reduced by decreasing the demand on the power supply. Savings of over 30% can be realised in VVVF controlled hydraulic lifts when the lift is running. VVVF drives can add to the standby power consumption and actually increase the overall energy consumption of the installation, especially in lifts with very low usage, like some residential lifts.
The major cause of energy consumption in traditional hydraulic lifts is, however, the absence of a counterweight to balance the car load. Until recently, it was only possible to install a counterweight in roped hydraulic lifts, but this had the disadvantage of increasing the load in the buildings structure. Instead of pushing the car directly, the piston pulls on the counterweight in order to move the car up.

Recently, bladder type hydraulic accumulators that act as a counterweight were introduced, thus allowing for a smaller motor to be used. These high-pressure gas filled tanks store energy during the car’s down travel by increasing the pressure of the gas in the accumulator.

Figure 3-35 shows a simplified representation of a system using hydraulic accumulators.

![Diagram of lift system using hydraulic counter-weight](source: Bucher Hydraulics)

In this system, a VVVF drive (3) controls a motor-pump (2) (1) assembly which pumps oil into a cylinder (7) to move the lift car. The valves are on/off controlled and the speed of the car is varied by varying the rotational speed of the pump, thus avoiding throttling losses. The position of the car is constantly monitored by a fine-resolution encoder located in the shaft (6). Variations in viscosity and pressure are compensated by the active control system for car position. During operation, the hydraulic accumulators act like a spring and release or store energy depending on the direction of travel, just like a mechanical counterweight would. This way a smaller motor can be used saving energy and reducing the power supply demand. Since the potential energy is transferred to the accumulator instead of being dissipated as heat, cooling is no longer necessary, which results in additional energy saving. Furthermore, since no significant heating of the hydraulic fluid occurs, these systems are capable of over 120 starts per hour against a maximum of 45 in conventional systems. Also, high-pressure is used (> 15 MPa) and, because of that, a smaller flow rate is needed and smaller components are used, making possible a compact Machine Roomless Design [16].

Manufacturers claim running energy savings of over 70%, compared to conventional hydraulic systems, when using the system described above. The energy consumption may be comparable to modern machine roomless traction lifts.
Further savings can be achieved by using a permanent magnet synchronous motor (PMSM) driving the pump and four quadrant running ability used in both pump and motor in both forward running and reverse running, allowing for regeneration [17].

When the cabin is travelling upwards, if the power from the accumulator is not enough, the variable-frequency-controlled electric motor can add power. In the same way, if the power from the accumulator is too much, the electric motor must be controlled to branch off a certain amount of power through the shaft of PMSM. The power that branched off can be fed back into the electric power network.

*Figure 3-36. Comparison of energy usage for 100,000 travels per year (source: Bucher Hydraulics)*
3.9 Efficient Escalators and Moving Walks

As in lifts, the efficiency of escalators’ components is of the utmost importance. High efficiency motors, drives, transmissions, bearings, etc. can yield significant savings and are, in most cases, cost-effective. As an example, planetary, helical, and hypoid helical gears can reach efficiencies of up to 96% and are now available from many manufacturers as a substitute for lower efficiency worm gears. Proper maintenance and lubrication of components also helps keep the equipments efficiency at its maximum.

Normally, escalators are always moving regardless of load conditions, causing energy wastage when there are no passengers to move. One of the biggest opportunities for improvement is, therefore, to adequately adjust the speed to the passenger demand at any given time by the use of variable-voltage or variable-voltage variable-frequency converter.

In the first option, the escalator is kept travelling at nominal speed. By reducing the voltage under low load conditions the magnetising current is also reduced, decreasing the motor iron losses, which are proportional to the square of the magnetic flux. Joule losses are also reduced while the power factor is increased. This type of equipment incorporates a soft-start and is small enough to replace the starter fitted in existing systems.

When using VVVF drive, the speed can be adjusted to match the passenger demand, thus reducing energy consumption and wear. Unlike other options (see below), VVVF drives provide very smooth, almost imperceptible speed transitions. Typically, three modes of operation are provided by variable speed escalators. After a predefined period of inactivity, escalators reduce their speed and reach the so called “reduced-speed” mode. The consumption in this “reduced-speed” mode is more or less half the consumption in the normal operation mode. After reaching this mode of operation, and after another predefined interval of time, the escalator is put into a STOP mode. At this STOP mode, only the control system and the passenger detection system (pressure mats, photocells or infra-red beams) are kept running. When a passenger is detected, the escalator slowly begins to move again, gently accelerating until it reaches nominal speed. Depending on the intensity of use of the escalator, this option can save up to 40% of the escalators energy consumption.

Simpler solutions are also available, but are not as attractive due to the lower travel comfort and limited energy savings:

- use of two-speed-motors
- switch the motor to star operation and supply it with lower voltage when there is low escalator traffic the motor. When several passengers enter the escalator the motor is switched back to delta operation.

Escalators can also be equipped with regenerative capability. Under ideal conditions, the energy needed to move the escalator in the upward direction would equal the energy provided by passengers travelling in the downward direction. Since losses are involved (friction losses, motor losses, drive losses, etc.) this is not the case. Nevertheless, regeneration in escalators can save up to 60% of the energy used by non-regenerative systems in very high
traffic demand installations. It should be noted that regeneration capability is inherent to induction motors connected directly to the power network, although the regeneration performance can be improved by the use of inverters.

3.10 Low Friction Bearings

Losses in bearings result from several types of friction (rolling friction loss, sliding friction loss, sealing friction loss and drag or lubricant shearing loss). A new generation of bearings is appearing in the market that can reduce these losses by 30% to 50% while extending the service life by a factor of two.

These bearings feature optimised internal geometry, a new polymer cage design that reduces rotational mass and cage deformation, low noise, as well as a low torque, and long lasting grease.

Energy-efficient bearings are now available for light and medium loaded applications, such as industrial electric motors driving machines (e.g. pumps, compressors, fans and conveyors), but solutions are currently being developed for lifts and escalators/moving walks that can respond to the specific needs of these systems (low speed, frequent starts and stops).

3.11 References


4 Market Characterisation

As part of the E4 Project, a survey was conducted with the cooperation of national lift and escalator associations in 19 European countries – Germany, Austria, Belgium, Czech Republic, Denmark, Finland, France, Greece, Hungary, Italy, Luxembourg, Netherlands, Poland, Portugal, Spain, Sweden, UK, Norway and Switzerland. The purpose of this survey was to assist in the characterisation of the installed base, according to the building type and basic characteristics of the installed units.

4.1 Lift Market

According to the surveys there are around 4,5 million lifts installed in the 19 countries surveyed. Figure 4-1 shows the distribution of the lifts installed in each of the surveyed countries, by sector.

![Figure 4-1. Lift distribution by sector](image)

Table 4-1 shows the total number of lifts installed and sold annually in each of the surveyed countries.
Table 4-1. Lift units installed and sold annually

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of lifts installed</th>
<th>No. of lifts sold annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>100,432</td>
<td>2,496</td>
</tr>
<tr>
<td>Belgium</td>
<td>75,000</td>
<td>2,553</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>112,000</td>
<td>1,920</td>
</tr>
<tr>
<td>Denmark</td>
<td>27,527</td>
<td>850</td>
</tr>
<tr>
<td>Finland</td>
<td>49,500</td>
<td>895</td>
</tr>
<tr>
<td>France</td>
<td>460,000</td>
<td>11,018</td>
</tr>
<tr>
<td>Germany</td>
<td>650,000</td>
<td>9,984</td>
</tr>
<tr>
<td>Greece</td>
<td>397,000</td>
<td>7,100</td>
</tr>
<tr>
<td>Hungary</td>
<td>29,800</td>
<td>1,170</td>
</tr>
<tr>
<td>Italy</td>
<td>850,000</td>
<td>13,400</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>7,917</td>
<td>410</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>85,300</td>
<td>2,913</td>
</tr>
<tr>
<td>Poland</td>
<td>81,683</td>
<td>3,410</td>
</tr>
<tr>
<td>Portugal</td>
<td>140,000</td>
<td>3,400</td>
</tr>
<tr>
<td>Spain</td>
<td>910,563</td>
<td>33,836</td>
</tr>
<tr>
<td>Sweden</td>
<td>129,000</td>
<td>1,310</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>247,000</td>
<td>7,079</td>
</tr>
<tr>
<td>Norway</td>
<td>35,300</td>
<td>833</td>
</tr>
<tr>
<td>Switzerland</td>
<td>151,500</td>
<td>5,995</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,539,522</strong></td>
<td><strong>110,572</strong></td>
</tr>
</tbody>
</table>

Figure 4-2 shows the distribution of the installed lifts according to building type. Residential lifts represent the by far the largest group with just under 2.9 million lifts in use. The Tertiary sector comes next with around 1,4 million lifts installed and the industrial sector has only 180,000 lifts.
Figure 4-2. Lift Distribution according to building type
Table 4-2. Average characteristics of European lifts

<table>
<thead>
<tr>
<th>Sector</th>
<th>Technology</th>
<th>No. of Units</th>
<th>Load (kg)</th>
<th>Rise (m)</th>
<th>Speed (m/s)</th>
<th>Motor Power (kW)</th>
<th>Trips /year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Hydraulic</td>
<td>699.340</td>
<td>461</td>
<td>16</td>
<td>0.8</td>
<td>8.7</td>
<td>44.900</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>2.118.866</td>
<td>392</td>
<td>17</td>
<td>1</td>
<td>4.8</td>
<td>62.300</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>94.310</td>
<td>608</td>
<td>22</td>
<td>1</td>
<td>6.0</td>
<td>131.000</td>
</tr>
<tr>
<td>Office</td>
<td>Hydraulic</td>
<td>176.515</td>
<td>693</td>
<td>23</td>
<td>0.9</td>
<td>16.7</td>
<td>164.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>330.323</td>
<td>703</td>
<td>25</td>
<td>1.4</td>
<td>12.7</td>
<td>232.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>121.570</td>
<td>760</td>
<td>33</td>
<td>1.6</td>
<td>11.7</td>
<td>242.000</td>
</tr>
<tr>
<td>Hospital</td>
<td>Hydraulic</td>
<td>29.712</td>
<td>1.264</td>
<td>12</td>
<td>0.7</td>
<td>11.8</td>
<td>278.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>147.410</td>
<td>1.258</td>
<td>17</td>
<td>1.1</td>
<td>11.8</td>
<td>382.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>26.050</td>
<td>1.275</td>
<td>28</td>
<td>1.3</td>
<td>19.4</td>
<td>565.000</td>
</tr>
<tr>
<td>Industrial</td>
<td>Hydraulic</td>
<td>52.914</td>
<td>1.817</td>
<td>13</td>
<td>0.6</td>
<td>24.5</td>
<td>43.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>134.547</td>
<td>1.120</td>
<td>12</td>
<td>0.6</td>
<td>15.0</td>
<td>73.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>241</td>
<td>1.160</td>
<td>8</td>
<td>1.0</td>
<td>17.9</td>
<td>27.600</td>
</tr>
<tr>
<td>Commercial</td>
<td>Hydraulic</td>
<td>57.314</td>
<td>963</td>
<td>14</td>
<td>1.1</td>
<td>15.2</td>
<td>142.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>169.035</td>
<td>920</td>
<td>12</td>
<td>1.1</td>
<td>14.6</td>
<td>192.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>15.822</td>
<td>945</td>
<td>11</td>
<td>1.3</td>
<td>11.9</td>
<td>224.000</td>
</tr>
<tr>
<td>Hotel</td>
<td>Hydraulic</td>
<td>30.926</td>
<td>1.024</td>
<td>15</td>
<td>0.6</td>
<td>16.3</td>
<td>86.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>114.232</td>
<td>873</td>
<td>18</td>
<td>0.9</td>
<td>10.3</td>
<td>199.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>23.702</td>
<td>1.114</td>
<td>24</td>
<td>1.6</td>
<td>15.4</td>
<td>220.000</td>
</tr>
<tr>
<td>Other</td>
<td>Hydraulic</td>
<td>20.173</td>
<td>1.024</td>
<td>14</td>
<td>0.67</td>
<td>8</td>
<td>144.000</td>
</tr>
<tr>
<td></td>
<td>Geared</td>
<td>114.410</td>
<td>873</td>
<td>20</td>
<td>1.1</td>
<td>8</td>
<td>298.000</td>
</tr>
<tr>
<td></td>
<td>Gearless</td>
<td>59.739</td>
<td>1.114</td>
<td>21</td>
<td>1.4</td>
<td>15</td>
<td>493.000</td>
</tr>
</tbody>
</table>

Note: When data from a country is missing or is insufficient it is derived from the data collected for other similar countries, or from the European average.
The next three figures show the lift distribution in each sector, according to the technology used.

**Residential Sector**

- Hydraulic: 3%
- Gearless Traction: 24%
- Geared Traction: 73%

**Tertiary Sector**

- Hydraulic: 27%
- Gearless Traction: 22%
- Geared Traction: 61%

Figure 4-3. Lift distribution according to the technology used in the residential sector

Figure 4-4. Lift distribution according to the technology used in the tertiary sector
According to ELA, there are approximately 75 thousand escalator units installed in the EU-27, of which 60 thousand units in commercial buildings and the rest in public transportation facilities (train stations, airports, etc.). It is estimated that 3,500 new units are installed each year.
5 Results of the Monitoring Campaign

A monitoring campaign was carried out within the E4 project as a contribution to the understanding of energy consumption and energy efficiency of lifts and escalators in Europe. The aim of this campaign is to broaden the empirical base on the energy consumption of lifts and escalators, to provide publicly available monitoring data and to find hints on high efficiency system configurations. Originally, 50 installations were planned to be monitored within the project. In the end, 74 lifts and 7 escalators, i.e. a total of 81 installations, were analysed in the four countries under study: Germany, Italy, Poland, and Portugal. Figure 5-1 shows the monitored installations by building category and country for all countries doing measurements in the project.

![Figure 5-1. Monitored lifts by building category (all monitored installations in the four countries)](image)

An effort was made to select lifts for this study from different years and using different technologies, in order to be able to compare the performance of a wide range of lifts with different characteristics. Figure 5-2 shows the segmentation of the units monitored by technology type.
Figure 5-2. Installations monitored by technology type

In this section, the results of the monitoring campaign are presented as well as a brief description of the methodology used for the measurements.

5.1 Methodology

For the measurement of the energy consumption of the lifts and escalators audited, and to ensure the repeatability of the measurements throughout the campaign, a methodology was developed, based on the following documents:

- EN 60359:2002 Electrical and electronic measurement equipment - Expression of the performance [2];
- Nipkow J. Elektrizitaetsverbrauch und Einspar-Potenziale bei Aufzuegen, Schlussbericht November 2005, Im Auftrag des Bundesamtes fuer Energie [3];
- Gharibaan Esfandiar, Load Factor for Escalators, EG (09/05/2008) [5].

Only a brief description of the methodology is made in this report, to help readers understand the basic procedures behind the measurements made. A detailed description of the methodology can be found on the project’s website (www.e4project.eu).

The aim of the measurements was to determine the direct energy consumption of the installation itself – in the case of a lift this includes the direct electrical power consumption of
the lift, but does not include additional equipment such as the machine room ventilation or shaft lighting. Thermal losses in buildings from shaft ventilation are also not part of the audits.

![Diagram of lift installation and measuring points](source: Fraunhofer-ISI)

**Figure 5-3. Lift installation and measuring points (marked orange)**

The electrical power demand of both the 3-phase power coupling for the drive circuit and the single phase power coupling for the lift ancillary circuit were monitored. Figure 5-3 shows the measuring points used for the German monitoring campaign. For some lifts it was not possible to differentiate between the two branches of power supply, e.g. for reasons of accessibility; for these installations, the energy consumption was measured before the splitting point (see Figure 5-1, Figure 5-3).

The methodology considers energy measurement relating to the normal operation of the lift, escalator and moving walk including:

a) Main energy - elevating/escalating/moving walk equipment such as: motor, frequency converter, controls, brake and door.

b) Ancillary energy - car auxiliary equipment such as: light, fan, alarm system, etc. Other consumption such as hoistway and machine room illumination, heating, ventilation and air conditioning were excluded from the measurements.

The reference measurement cycle for lifts, starting at the bottom landing, consists of:

1. Opening the Door
2. Closing the Door
3. Driving the car from the bottom landing to the top landing, without passengers
4. Opening the Door
5. Closing the Door
6. Driving the car from top landing to the bottom landing, without passengers
7. Opening the Door
8. Closing the Door

The total running energy consumption per one cycle is calculated using the recorded values of active power and time ($E = \int_{t=0}^{t=r} P \, dt$).

The measurement of the standby energy consumption starts 5 minutes after the last movement of the car.

Both values, running energy and standby energy, are combined with usage patterns to estimate the annual energy consumption, in kWh, of the installation.

$$E_{\text{lift}} = c_{\text{amf}} \times \frac{c_{\text{std}} \times E_{\text{cycle}} \times 2 \times (1 - c_{\text{bal}})}{1000 \, \text{W/kW}} \times n_{\text{trip}} + E_{\text{standby}}$$

Where,

- $E_{\text{lift}}$: Energy used by the lift in one year [kWh/year]
- $c_{\text{amf}}$: Average motor load factor.
- $c_{\text{std}}$: Average travel distance factor (1; 0.5 or 0.3)
- $h$: Rise height [m]
- $n_{\text{trip}}$: Trips per year [1/year]
- $E_{\text{standby}}$: Standby Energy used in 1 year [kWh/year]
- $E_{\text{cycle}}$: Energy for a cycle trip [Wh]
- $c_{\text{bal}}$: Balancing factor

The annual standby energy used is calculated in the following way:

$$E_{\text{standby}} = \left( \frac{8760 \, \text{h}}{\text{1 y}} - \frac{c_{\text{std}} \times h \times n_{\text{trip}}}{\text{v}} \right) \times \frac{1 \, \text{h}}{3600 \, \text{h}} \times \frac{1 \, \text{kW}}{1000 \, \text{W}} \times P_{\text{standby}}$$
Where,

\[ E_{\text{standby}} \] Standby Energy used in 1 year [kWh/year]
\[ c_{\text{std}} \] Average travel distance factor (1, 0.5 or 0.3)
\[ h \] Rise height [m]
\[ n_{\text{trip}} \] Trips per year [1/year]
\[ P_{\text{standby}} \] Standby Power [W]
\[ v \] Speed of lift [m/s]

All measurements are made with an empty car. Since lifts do not run empty all the time under real conditions, adjustments via a typical load collective\(^2\) were done. The average motor load factor \( C_{\text{aml}} \), as shown in Table 5-2 is used for this calculation.

**Table 5-1. Load collective**

<table>
<thead>
<tr>
<th>Load</th>
<th>Direction of travel</th>
<th>Share of trips in this direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>Upwards</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Downwards</td>
<td>0%</td>
</tr>
<tr>
<td>75%</td>
<td>Upwards</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Downwards</td>
<td>5%</td>
</tr>
<tr>
<td>50%</td>
<td>Upwards</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Downwards</td>
<td>5%</td>
</tr>
<tr>
<td>25%</td>
<td>Upwards</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Downwards</td>
<td>15%</td>
</tr>
<tr>
<td>0%</td>
<td>Upwards</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Downwards</td>
<td>25%</td>
</tr>
</tbody>
</table>

The average motor load factor \( C_{\text{aml}} \) is the statistical average in which the motor or drive system has to operate. It is dimensionless, since it is the ratio between average motor load and maximum possible motor load.

**Table 5-2. Average motor load factor \( C_{\text{aml}} \)**

<table>
<thead>
<tr>
<th>Lift technology</th>
<th>( C_{\text{aml}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction lifts 50% balanced no regenerative drive systems</td>
<td>0.35</td>
</tr>
<tr>
<td>Traction lifts 50% balanced with gearless regenerative drive systems</td>
<td>0.35</td>
</tr>
<tr>
<td>Hydraulic lifts without counterweight</td>
<td>0.30</td>
</tr>
</tbody>
</table>

\(^2\) The high share of empty travelling is explainable by the fact that a lift often travels empty to destination it is called to.
To take into account the effect of the counterweight, a balancing factor is used, as shown in Table 5-3.

**Table 5-3. Balancing factor \( c_{\text{bal}} \)**

<table>
<thead>
<tr>
<th>Type of Lift</th>
<th>( c_{\text{bal}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction lift 50% balanced</td>
<td>0.50</td>
</tr>
<tr>
<td>Hydraulic lift no balanced</td>
<td>0</td>
</tr>
</tbody>
</table>

Since precise information about the use of the lift in the building is not readily available, the following assumptions for the calculation of the lifts travel distance are taken:

**Table 5-4. Average travel distance factor \( C_{\text{std}} \)**

<table>
<thead>
<tr>
<th>Quantity of stops</th>
<th>Average Travel Distance ( C_{\text{std}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 stop building</td>
<td>maximum travel distance (lowest to topmost floor)</td>
</tr>
<tr>
<td>more stop building</td>
<td>0.5 * maximum travel distance (lowest to topmost floor)</td>
</tr>
<tr>
<td>more than one lift forming a group of lifts in a more than 2 stop building</td>
<td>0.3 * maximum travel distance (lowest to topmost floor)</td>
</tr>
</tbody>
</table>

For the measurement of active power escalators/moving walks are run for 5 minutes in the up/forward direction and for another 5 minutes in low-speed mode (when existing). The standby power in escalators is measured with the escalator/moving walk stopped.

Once again, both values, running energy and standby energy, are combined with usage patterns to estimate the annual energy consumption of the installation.

For escalators, the power consumption was determined in different states of operation. These modes of operation include measurements over a period of 5 minutes when running at nominal speed, in a stop mode, and, finally, if available, in a low speed mode. Measurements were made to empty escalators only. To take passenger load into account, as found in real systems, annual consumption values were calculated by multiplying running-consumption with a typical load factor.

### 5.2 Monitoring Results

Analysing energy consumption and energy demand and especially comparing different installations is a challenging task due to the high number of different factors contributing to the overall energy consumption of a lift installation.
Figure 5-4 shows a typical cycle of a traction lift.

Figure 5-4. Typical cycle of a traction lift.

The initial transient, typical of a direct starting of an AC motor, is evident. In this case, the starting active power reaches more than several times the nominal active power of the motor. During the “travelling down” it is necessary to overcome the difference of weight between the lift car (in this case empty) and the counterweight. When “travelling up”, since the counterweight is heavier than the lift car, the necessary active power is quite reduced. After arriving at the end of each trip, there is a peak in the active power corresponding to the braking of the motor driven system.

The typical cycle of a hydraulic lift is illustrated in Figure 5-5.
Figure 5-5. Typical cycle of a hydraulic lift.

When “travelling down”, the total active power required by the hydraulic lift system is practically imperceptible when compared with the standby consumption. This small consumption is mainly due to the maintenance of the pressure of the hydraulic fluid. As mentioned above, the “travelling down” for a hydraulic lift, corresponds to the opening of the valve to let the hydraulic fluid flow back to the tank.

The travel cycle consumption of a lift is greatly dependant on the number of floors, the technology used, weight in the car, etc. In the following figures, the energy consumption for one reference travel cycle of each of the audited lifts is presented, by sector.
Figure 5-6. Travel cycle consumption of the lifts audited in the tertiary sector.

Figure 5-7. Travel cycle consumption of the lifts audited in the residential sector.
It is clear that there are large differences between the cycle consumption of the different lifts analysed. Even if this consumption is compared with lifts of the same rise height, velocity or nominal load the conclusions are not clear about what technology is the most efficient one, as there are a lot of factors to be included, such as lighting, type of control, etc.

The measured standby power varies widely, as can be seen in Figures 5-9 to 5-11. This standby consumption is due to the control systems, lighting, floor displays and operating consoles in each floor and inside the lift cabin. In the audited lifts the standby power ranges from 15 W to 710 W.
Figure 5-9. Measured standby power in the lifts audited in the tertiary sector

Figure 5-10. Measured standby power in the lifts audited in the residential sector
The standby consumption is particularly dependant of the type of lighting used in the cabin (incandescent, fluorescent or compact fluorescent) and its control. In some lifts analysed, the cabin lift lights are switched off a few seconds after the cycle is over. In other cases, these lights are left on 24 hours a day.

The E4-methodology provides a method to estimate the annual energy consumption of the monitored installations. The results presented in Figures 5-12 to 5-17 result from the combination of the above given consumption values for the reference cycle, standby power and the annual number of trips.
Figure 5-12. Annual Energy consumption of the lifts audited in the tertiary sector

Figure 5-13. Proportion of standby and running mode to overall energy consumption of lifts in the tertiary sector
Figure 5-14. Annual Energy consumption of the lifts audited in the residential sector

Figure 5-15. Proportion of standby and running mode to overall energy consumption of lifts in the residential sector
Figure 5-16. Annual Energy consumption of the lifts audited in the industrial sector

Figure 5-17. Proportion of standby and running mode to overall energy consumption of lifts in the industrial sector

It is clear that standby consumption in lifts is a very important issue. Standby consumption represents between 4.2% and 90.2% of the overall consumption of the lift.
It is important to notice that the usage pattern has an important influence in the relation between the standby power and running mode energy consumption of lifts. The higher the number of trips per year, the higher the contribution of the running mode consumption to the overall energy consumption of the installation.

The next figure illustrates the various states of operation of an escalator equipped with a variable speed drive.

![Active power of an escalator in different operation modes](image)

**Figure 5-18. Active power of an escalator in different operation modes**

Typically, three modes of operation are provided by variable speed escalators. After a predefined period of inactivity, escalators reduce their speed and reach the so called “reduced-speed” mode. The consumption in this “reduced-speed” mode is more or less half the consumption in the normal operation mode. After reaching this mode of operation, and after another predefined interval of time, the escalator is put into a STOP mode. At this STOP mode, only the control system and the passenger detection system (pressure mats, photocells or infra-red beams) are kept running. When a passenger is detected, the escalator slowly begins to move again, gently accelerating until it reaches nominal speed. According to the developed methodology, the standby consumption is considered to be the summation of the low-speed mode consumption and the stop mode consumption.

**Figure 5-19** shows the estimated annual electricity consumption of the escalators monitored.
Figure 5-19. Annual electricity consumption of the monitored escalators

5.3 References


6 Estimation of Potential Savings

This chapter presents the results of the estimation of the electricity consumption of existing lifts and escalators in Europe, as well as of the savings potential made possible by the use of the best available technologies in the market today.

The characterisation of the installed base according to building type and basic characteristics was made, as part of Work Package 2, by means of a survey conducted in cooperation with the national member associations of the European Lift Association (ELA, presented in chapter 4).

Typical values for the electricity consumption of lifts are based on the monitoring campaign carried out during this project (Work Package 3), in a number of selected buildings of the residential, tertiary and industrial sectors, taking into consideration typical lift and escalator technologies in use. A total of 81 equipments have been measured by the project’s partners (ENEA, Fraunhofer-ISI, KAPE and ISR-UC) in the four countries concerned: Italy, Germany, Poland, and Portugal.

With respect to the achieved values of potential savings, it is important to notice that:

- The initial cost of the technologies used, while being an important issue regarding their application, has not been considered in this report; therefore, no indications are provided about cost-effectiveness of those technologies;

- Maintenance costs, such as labour and spare-parts, have not been included in the calculations, even if some of the electronic components in inverters (e.g. cooling fans, capacitors, internal relays) ought to be periodically serviced in order to avoid degradation in the inverter’s performance;

- Some technologies may increase standby consumption while reducing consumption during the running phase. Therefore, their application should be carefully evaluated on a specific-case basis.

6.1 Methodology for lifts

The proposed methodology is applied for each sector and for each of the main technologies (hydraulic, geared traction, and gearless traction) used, consisting of four parts:

1. Determination of the average characteristics of the lifts used;

2. Estimation of the annual running energy consumption;

3. Estimation of the annual standby energy consumption;

4. Estimation of the potential savings by using the best available technologies in the market.

The total values are then calculated by the aggregation of the sectoral values.
6.1.1 Determination of the average characteristics of the lifts used

For each sector and for each of the technologies used – Hydraulic, Geared Traction and Gearless Traction – the average lift characteristics are calculated, based on the results of the surveys undertaken in WP2, which provide the relevant information about the lifts used in Europe.

The key average characteristics of these lifts are the result of the averages of the lift installed base:

a) Average motor power  
b) Average load  
c) Average rise  
d) Average speed  
e) Average number of trips per year

Averages are calculated based on the weighted assessment with the number of units, by each type.

6.1.2 Estimation of the annual running baseline energy consumption

1. Based on the measurements conducted in WP3, the average value for the energy consumed in each cycle ($E_{cycle}$) for each lift technology is considered, in each sector.

2. Calculate the running energy consumed annually by each lift technology ($E_{rin}$) using the Methodology defined in WP3 (see chapter 5).

3. Calculate the annual consumption for each technology used

$$E_{tech} = E_{rlift} \cdot n_{units}$$

4. Calculate the annual consumption for each sector, which is the sum of $E_{tech}$ for each of the technologies used (hydraulic, geared traction, gearless traction).
6.1.3. Estimation of the annual Stand-by Energy consumption

1. For each average lift technology consider the average of the standby power of the lifts audited during WP3 with similar characteristics.

Table 6-2. Average Stand-by power of the monitored lifts (W)

<table>
<thead>
<tr>
<th></th>
<th>Hydraulic</th>
<th>Geared</th>
<th>Gearless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>180.4</td>
<td>163.8</td>
<td>249.0</td>
</tr>
<tr>
<td>Office</td>
<td>182.9</td>
<td>244.8</td>
<td>320.7</td>
</tr>
<tr>
<td>Hospital</td>
<td>339.6</td>
<td>244.1</td>
<td>163.7</td>
</tr>
<tr>
<td>Industrial</td>
<td>253.1</td>
<td>436.5</td>
<td>--</td>
</tr>
<tr>
<td>Commercial</td>
<td>--</td>
<td>--</td>
<td>235.1</td>
</tr>
<tr>
<td>Hotel</td>
<td>113.6</td>
<td>198.5</td>
<td>204.3</td>
</tr>
</tbody>
</table>

1. Calculate the standby energy consumed annually by each lift \( E_{sift} \) using the Methodology defined in WP3 (Paragraph 7).

2. Calculate the annual consumption for each technology used

\[
E_{stech} = E_{sift} \cdot n_{units}
\]

3. Calculate the annual consumption for each sector, which is the sum of \( E_{stech} \) for each of the technologies used (hydraulic, geared traction, gearless traction).

6.1.4. Estimation of savings potential – Running

1. Assume the Best Available efficiencies for each of the components in the lift:
   - Motor efficiency: 15% lower losses than IE3 in IEC60034-30 (Super Premium or Permanent Magnet Synchronous Motors)
   - Efficiency of helical gear – 96%
   - Friction losses (5%)
   - Efficiency of VSD (95%)

2. For the existing installed units calculate the overall value of efficiency and the energy consumed in each cycle for each lift technology.

From the values of \( E_{cycle} \) used in previous section 2 (Estimation of the annual running baseline energy consumption) calculate the mechanical power required by each of the lifts:

\[
P_{mech} = E_{cycle} \cdot \eta_{system} \cdot \frac{v}{h}
\]
Where,

\[ \begin{align*}
    P_{\text{mech}} & \quad \text{Mechanical power on the load [W]} \\
    E_{\text{cycle}} & \quad \text{Energy for a cycle trip [Ws]} \\
    \eta_{\text{system}} & \quad \text{Efficiency of the system} \\
    h & \quad \text{Rise height [m]} \\
    v & \quad \text{Speed of lift [m/s]} \\
\end{align*} \]

For the typical efficiency of each of the existing system’s components consider:

- Motor efficiency: same as EFF3 efficiency threshold in CEMEP/EU agreement or IE1 in IEC60034-30 (more conservative)
- Efficiency of worm gear – 60% (geared systems)
- Efficiency of 2:1 roping arrangement 90% (normally used in gearless systems)
- Efficiency of pump 70% (hydraulic lifts)
- Friction losses (5%)
- Efficiency of Variable Speed Drive (VSD) (90%)

Calculate the energy used in each cycle by using the Best Available efficiencies for each of the components in the lift:

\[
    E_{\text{cycle}} = \frac{P_{\text{mech}}}{\eta_{\text{improved}}} \cdot \frac{h}{v}
\]

Where,

\[ \begin{align*}
    E_{\text{cycle}} & \quad \text{Energy for a cycle trip [Ws]} \\
    P_{\text{mech}} & \quad \text{Mechanical power on the load [W]} \\
    \eta_{\text{improved}} & \quad \text{Efficiency of the system using the best available technologies} \\
    h & \quad \text{Height of rise [m]} \\
    v & \quad \text{Speed of lift [m/s]} \\
\end{align*} \]

3. Calculate the energy consumed annually by each lift \(E_{\text{r.lift}}\) technology using the Methodology defined in WP3 (see Chapter 5).

4. Calculate the annual consumption for each technology used

\[
    E_{\text{r.tech}} = E_{\text{r.lift}} \cdot n_{\text{units}}
\]

5. Calculate the annual consumption for each sector, which is the sum of \(E_{\text{r.tech}}\) for each of the technologies used (hydraulic, geared traction, gearless traction).

6.1.5. Estimation of savings potential – Stand-by

For the estimation of the standby savings potential two scenarios are considered:

**BAT - Best Available Technologies**

Best Available Technologies are the best existing components currently being commercialised.
1. Consider the best available technologies for each of the components which contribute to the standby energy consumption:

- LED Lighting (varies from 12 W for lift with load 320 kg to 18 W for 1,000 kg load lift)
- Electronic Controllers (25 W)
- Inverter (20 W)
- Door operators (5 W)
- Buttons and Displays

2. Calculate the energy consumed annually by each lift using the Methodology defined in WP3 (Paragraph 7).

3. Calculate the annual consumption for each technology used

\[ E_{\text{tech}} = E_{\text{stift}} \cdot n_{\text{units}} \]

4. Calculate the annual consumption for each sector, which is the sum of \( E_{\text{tech}} \) for each of the technologies used (hydraulic, geared traction, gearless traction).

**BNAT – Best Not Available Technologies**

Best Not Available Technologies are state-of-the-art technologies that are currently being developed, but that are not yet commercially available.

1. Consider turning off of all non-essential components which contribute to the standby energy consumption when the lift is not in use.

2. Consider putting the controller and inverter into sleep-mode (1 W each).

In the calculation of standby energy consumption, a 15 second period is added to the travel time to establish the time spent in sleep-mode taking into account the time lapse before shutting down non-essential components. In this scenario, the same assumptions and method as in scenario 1 are used.
6.2. Electricity consumption of lifts in Europe

According to the characterisation of the lifts’ installed base conducted as part of Work Package 2 of the E4 project, there are around 4.5 million lifts installed in the 19 countries surveyed.

The data obtained with the survey of the WP2, related to 19 countries, were adjusted to EU-27, plus Switzerland and Norway. Using the methodology previously described the total electricity consumed by lifts is estimated to be 18,4 TWh, of which 6,7 TWh are in the residential sector, 10,9 TWh in the tertiary sector and only 810 GWh in the industrial sector.

Figure 6-1 shows the running and standby estimated annual energy consumption of European lifts in the residential and tertiary sector. Although the number of lifts installed in the tertiary sector is smaller, their energy consumption is far bigger than the one in the residential sector due to their more intensive use.

Table 6-3. Number of lifts installed (EU-27)

<table>
<thead>
<tr>
<th></th>
<th>Hydraulic</th>
<th>Geared Traction</th>
<th>Gearless Traction</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>743.979</td>
<td>2.254.112</td>
<td>100.330</td>
<td>3.098.421</td>
</tr>
<tr>
<td>Tertiary</td>
<td>333.248</td>
<td>946.208</td>
<td>270.344</td>
<td>1.549.801</td>
</tr>
<tr>
<td>Industrial</td>
<td>49.312</td>
<td>126.397</td>
<td>227</td>
<td>175.936</td>
</tr>
<tr>
<td>Total</td>
<td>1.126.539</td>
<td>3.326.718</td>
<td>370.901</td>
<td>4.824.157</td>
</tr>
</tbody>
</table>

Figure 6-1. Lift annual electricity consumption

As it can be seen, the standby energy consumption represents an important share of the overall energy consumption, especially in lifts installed in the residential sector, where the time spent in standby mode is longer. The next figure presents the standby consumption and the running mode consumption, in proportion to the overall consumption in the residential and the tertiary sectors.
Figure 6-2. Proportion of standby and running mode to overall energy consumption of lifts

Figure 6-3. Total energy consumption by technology used
6.3. Estimation of potential savings - Lifts

The estimation of the potential savings in lifts is made according to the previously described methodology by assuming two scenarios: 1. that the Best Available Technologies (BAT) are used; 2. that the Best Not yet Available Technologies (BNAT) are used. It is important to notice that the initial cost of the technologies used, while being an important issue regarding their application, is not considered in this report.

The next table and figures show the estimated electricity consumption, by sector, according to the different scenarios proposed in the methodology.

Table 6-4. Estimated energy use of lifts by sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Scenario</th>
<th>Running Mode (GWh)</th>
<th>Standby Mode (GWh)</th>
<th>Total (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Existing technologies</td>
<td>2.119</td>
<td>4.545</td>
<td>6.664</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>880</td>
<td>1.673</td>
<td>2.553</td>
</tr>
<tr>
<td></td>
<td>BNAT</td>
<td>880</td>
<td>196</td>
<td>1.370</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Existing technologies</td>
<td>6.346</td>
<td>4.558</td>
<td>10.903</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>3.224</td>
<td>884</td>
<td>4.131</td>
</tr>
<tr>
<td></td>
<td>BNAT</td>
<td>3.224</td>
<td>341</td>
<td>3.558</td>
</tr>
<tr>
<td>Industrial</td>
<td>Existing technologies</td>
<td>209</td>
<td>603</td>
<td>812</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>129</td>
<td>106</td>
<td>235</td>
</tr>
<tr>
<td></td>
<td>BNAT</td>
<td>129</td>
<td>15</td>
<td>144</td>
</tr>
<tr>
<td>Total</td>
<td>Existing technologies</td>
<td>8.673</td>
<td>9.706</td>
<td>18.379</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>4.256</td>
<td>2.663</td>
<td>6.919</td>
</tr>
<tr>
<td></td>
<td>BNAT</td>
<td>4.256</td>
<td>552</td>
<td>4.808</td>
</tr>
</tbody>
</table>

Figure 6-4. Estimation of the Electricity consumption of lifts according to different scenarios in the residential sector
Figure 6-5. Estimation of the Electricity consumption of lifts according to different scenarios in the Tertiary sector

Figure 6-6. Estimation of the Electricity consumption of lifts according to different scenarios in the industrial sector

Figure 6-7. Estimation of the total Electricity consumption of lifts according to different scenarios
The results show that overall savings of more than 65% are possible. A reduction of over 11 TWh is achieved using the Best Technologies Available and of 13 TWh when technologies that are currently being developed are used, which translates into a reduction of around 4,9 Mtons of CO$_{2eq}$ and 5,8 Mtons of CO$_{2eq}$, respectively, with the current electricity production methods.

Savings in the standby energy consumption are particularly noticeable even in the BAT scenario where although low power equipment is used it is always kept on even when it is not in use, as it is presently the common practice. A reduction in standby power of over 70% is considered feasible with off-the-shelf technologies. In particular, the use of LED lighting can play a major role in this reduction.
6.4. Electricity consumption of Escalators and Moving Walks in Europe

According to ELA statistics, there are 75,000 escalators and moving walks installed in the EU-27. Based on the surveys conducted in WP2, two assumptions are made:

- 75% of the escalators are installed in commercial buildings and the remaining 25% in public transportation facilities.
- 30% are equipped with a Variable Speed Drive (VSD)

Based on the measurements conducted in WP3, the average value for the electricity consumed during running and standby modes (slow-speed and stopped), is considered.

Table 6-5. Average electricity consumption in each operating mode

<table>
<thead>
<tr>
<th>Escalator</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Energy-Running, 5 minutes test (Ecr) [Wh]</td>
<td>162,1</td>
<td>186,37</td>
<td>127,34</td>
<td>172,58</td>
<td>131,18</td>
<td>166,31</td>
<td>164,55</td>
<td>158,6</td>
</tr>
<tr>
<td>Active Energy-Standby in a LOW SPEED mode, 5 minutes test (EcsL) [Wh]</td>
<td>n.a.</td>
<td>82,42</td>
<td>n.a.</td>
<td>80,87</td>
<td>44,54</td>
<td>n.a.</td>
<td>n.a.</td>
<td>69,3</td>
</tr>
<tr>
<td>Active Power - Standby in a STOP mode (Pss) [W]</td>
<td>53,3</td>
<td>43,53</td>
<td>30,73</td>
<td>50</td>
<td>16,87</td>
<td>38,84</td>
<td>40,93</td>
<td>39,2</td>
</tr>
</tbody>
</table>

Only escalators in commercial buildings were monitored. Based on ELA experts’ opinion, it is considered that escalators in public transportation facilities consume 75% more electricity than escalators in commercial buildings. The time spent in each operating mode is assumed as shown in the next table.

Table 6-6. Time spent in each operating mode

<table>
<thead>
<tr>
<th>Escalator</th>
<th>Commercial</th>
<th>Public Transportation</th>
<th>Commercial</th>
<th>Public Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running (h)</td>
<td>4368</td>
<td>7280</td>
<td>1872</td>
<td>2912</td>
</tr>
<tr>
<td>Slow-speed (h)</td>
<td>0</td>
<td>0</td>
<td>2496</td>
<td>4368</td>
</tr>
<tr>
<td>Stopped (h)</td>
<td>4392</td>
<td>1480</td>
<td>4392</td>
<td>1480</td>
</tr>
</tbody>
</table>

The energy consumed annually is calculated using the Methodology defined in WP3 (Chapter 5) and shown in Table 6-7.

Table 6-7. Estimated escalator electricity consumption

<table>
<thead>
<tr>
<th>Escalator</th>
<th>Commercial Buildings</th>
<th>Public Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>With inverter</td>
<td>ERunning (GWh)</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>EStandby (GWh)</td>
<td>38</td>
</tr>
<tr>
<td>Without inverter</td>
<td>ERunning (GWh)</td>
<td>354</td>
</tr>
<tr>
<td></td>
<td>EStandby (GWh)</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.5. Estimation of Savings Potential - escalators and moving walks

For the estimation of energy savings it is considered that all of the escalators installed would be equipped with VSD. Furthermore, it is considered that when stopped, the controller and inverter only consume one Watt each.

Table 6-8. Estimated escalator electricity consumption using best available technologies.

<table>
<thead>
<tr>
<th></th>
<th>Commercial Buildings</th>
<th>Public Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>With inverter</td>
<td>Erunning (GWh)</td>
<td>217</td>
</tr>
<tr>
<td></td>
<td>EStandby (GWh)</td>
<td>117</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A potential reduction in the electricity consumption of around 255 GWh (28%) would be possible and it would mean a reduction of 100,000 ton per year in CO$_2$eq emissions.
7 Strategies for Market Transformation for EE Lift and Escalator

According to findings of this project, a considerable saving potential exists both for lifts and escalators that could be realised, if the appropriate technology is chosen (see Chapter 6). The savings from realising this potential would not only reduce electricity consumption directly and the environmental impact of lifts and escalators indirectly, but they may also lead to economic savings through lower energy bills. However, energy-efficient technology is spreading slowly throughout the market – a phenomenon which could be explained by barriers in the market.

Against this background, this section has three aims. First, it systematically analyses possible barriers to the diffusion of energy-efficient technology in the European lift and escalator market. This analysis is based on an interview study as well as on validating discussions with market actors. Second, on top of this analysis, it identifies possible strategies and tools to overcome the barriers identified in the first step. As part of these strategies, suitable measures as well as relevant market transformation mechanisms are addressed. Third, it provides guidelines on how to improve the energy efficiency for existing and new installations.

7.1 Barriers to Energy-Efficient Technologies

7.1.1 The European lift and escalator market

This section gives an overview of the lift and escalator market in Europe and identifies relevant market actors.

Four companies, i.e. KONE, Schindler, Otis, Thyssen-Krupp, hold high market shares for elevators and for escalators [1]. Those companies tend to offer standardised products or at least standardised components on a grand scale. The remaining market consists of many small- and middle-sized enterprises that either concentrate on a certain region or provide specialised products. Manufacturers strongly compete for maintenance contracts, thus offering not only lifts or escalators as a product, but as a part of a general service package. The transformation of the market from a manufacturing to a service-oriented sector is often seen as completed.

For new installations, the development and the profitability of the lift and escalator market largely depend on the construction industry which is known to depend strongly on general economic growth. Additionally, in the past, strong competition took place, lowering prices for new installations [1]. Maintenance as well as modernisation of the existing stock is more stable, thus providing constant income for the companies in the market.

Regarding technological innovations, market transformation is usually slow, as lifts and escalators are products with a long lifetime. For lifts, it may take up to 15-30 years before major retrofitting is necessary [2]. This needs to be taken into account when formulating strategies to strengthen the market penetration of energy-efficient technology.

Identification of stakeholders and actors

Besides manufacturing and maintenance companies, as well as users of lifts and escalators, several additional stakeholders and actors may be involved in the process of choosing a new
installation or in the decision-making processes related to retrofitting an existing one (see Figure 7-1 for an overview of stakeholders). To a lesser or higher degree, all of these stakeholders influence the energy efficiency of the equipment and therefore need to be taken into account.

Manufacturing companies often act as full service companies, offering everything from support in planning and choosing a new installation up to repair and maintenance and finally retrofitting. Thus their influence on the energy efficiency of an installation is probably extensive, as they are involved in all stages. Increasingly, manufacturers rely on the support of contracted companies for the installation of new equipment – thus adding an additional actor.

On the buyer side, in the case of a new building, first of all, the decision has to be taken, whether to include a lift or escalator or not. Increasingly, national or regional legislation and regulation recommend including equipment to ensure accessibility to buildings for all groups of individuals. In the next step, the number, size and location of installations has to be determined. Within this step, besides the construction company and the architect, construction engineers as well as lift consultants may be involved in dimensioning and situating lifts and escalators.

After completing the building, operators and administrators for the building and the technical installations come into play as well as service and maintenance personnel, either from the lift and escalator industry or as separate companies. Depending on the type of building and its use, the final owner may also be the user of an installation, e.g., in the residential sector, if a building is commonly owned by its occupants. However, in other cases, the owner may hardly or never use the installation, e.g. in case of a shopping mall which is owned by an investment company. In any case, all of these stakeholders are crucial when it comes to monitor the energy consumption of an existing installation as well as to initiating a retrofit. However, their networking and interaction as well as their influence may vary significantly.

Banks are often part of the process as well, as financiers of the whole process. Although it is very unlikely that they will directly influence the choice of model for a lift or escalator, they may exert influence by limiting the amount of capital that is available for investment.

A probably more significant role is played by notified bodies as well as market surveillance. Notified bodies like the German and Austrian TÜV, the Dutch Lifstituut or the British SAFed are involved, as they are certified to check the safety of installed equipment and may thereby initiate a retrofit. Additionally, companies and institutions which hold these kinds of certificates are also often engaged in research and in dissemination of information. Thus they are a possible source of data regarding energy efficiency. Market surveillance hardly influences energy consumption from the perspective of an individual installation.

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3 For example. the German norm DIN 18024-2.

4 The term ‘final owner’ refers to the fact that buildings may be owned by a construction company, general contractor or investment company during their development and construction phase, but however be sold to another organization or individual after completion.
6.5.3. Methodology

To gain additional knowledge beyond the one found in the available literature and facts already accumulated by prior work packages, expert interviews were conducted, in a first step. These interviews were then complemented with written surveys undertaken by two of the project partners, ISR-UC and KAPE. In a second step, the results from the interviews were discussed with the project team and with ELA members, thus validating the information obtained and the conclusions drawn. This process of verifying data is also called 'triangulation' [3].

Thus, for the purpose of this study, the list of stakeholders identified above was taken as a starting point and condensed to identify relevant experts, resulting in five categories of stakeholders (cp.Table 7-1).
Table 7-1. Categories of stakeholders identified and actual coverage of interviews and survey.

<table>
<thead>
<tr>
<th>Stakeholder categories</th>
<th>Number of Interviews</th>
<th>Survey participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer, installation, service &amp; maintenance</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Architect, construction engineers, lift consultants</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Construction company</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Building administrator and operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Notified bodies</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

In sum, 13 interviews were conducted by ISI and 10 written surveys were collected by ISR-UC and KAPE (6 and 4, respectively). The experts surveyed represented several European countries, e.g. Germany, Switzerland, Italy, Portugal, and Poland. The European perspective is further broadened by two interviews conducted with representatives of European professional and industrial associations working in Brussels/Belgium.

The interviews were usually conducted via telephone in German or English. An interview guideline was provided beforehand, based on a literature analysis [4] [5]. The guideline consisted of five parts. *Part A* asked participants to do a general assessment of the lift and escalator market regarding the salience of energy efficiency in the market, the most important criteria when choosing equipment, and differences between the lift and the escalator market. We also asked whether the interview partner thinks that investment in energy-efficient technology in this sector pays off financially. *Part B* listed barriers – extracted from the literature – and asked participants for an opinion whether they thought that a barrier applies 1) never or only in very few cases, 2) in some cases 3) in most cases. If they chose 3, they were then asked to comment in more detail on this issue. The list of barriers is presented in Table 7-2.

Table 7-2. List of barriers rated in the interviews.

<table>
<thead>
<tr>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information and transaction costs</strong></td>
</tr>
<tr>
<td>- Operators of lifts or escalators do not monitor the energy consumption and the energy costs of their installations.</td>
</tr>
<tr>
<td>- Operators do not have a designated employee who is responsible for the energy-related issues of lifts and escalators.</td>
</tr>
<tr>
<td>- The decision-maker is not aware of the energy consumption of the choice he or she makes.</td>
</tr>
<tr>
<td>- It is difficult or impossible for the decision-maker to obtain information about energy-efficient technology.</td>
</tr>
</tbody>
</table>
**Split incentives**
- The energy costs for a lift or escalator are paid by someone other than the person who chooses the equipment.
- Do you think that the person who chooses the components would use more energy-efficient components if the final operator had more information about the energy consumption of the installation?

**Bounded rationality**
- The decision-maker tends to select less energy-efficient equipment due to a lack of time.
- Investors select lifts based on their investment rather than on their life-cycle costs.

**Capital**
- Investors lack capital to invest in energy-efficient technology.
- In case of retrofits: investors lack capital to replace existing lifts or escalators in favour of better technology that would be less expensive in the long run.
- Budgeting laws cause public investors to select less energy-efficient technology.

**Risks and uncertainty**
- Changing energy prices may affect the economic profitability of investments in energy-efficient technology. This is a reason for the market not to invest in energy-efficient lifts and escalators.
- Energy efficiency competes against other functional specifications of the system, such as safety and comfort.
- Energy-efficient technology is seen as more vulnerable to disruptions of operations.
- Energy-efficient technology is perceived as increasing needs for repair and maintenance.
- Energy-efficient technology in escalators and lifts leads to significant new requirements for the training of technical personnel for producers, service companies or lift administrators.
- Investors in energy-efficient technology were disappointed by broken promises about the saving potential of new technology that did not meet expectations after the equipment was put into operation.

**Part C** consisted of questions regarding differences between new installations and retrofits, analysing this topic in more detail. **Part D** inquired about strategies and tools for market transformation. And the final part, **Part E**, asked – from the participant’s point of view – whether all relevant issues had been touched on.

The questionnaires for the survey administered by the project partners ISR-UC and KAPE were very similar to the guideline used for the interviews. An English version of the questionnaire was translated into Portuguese and Polish and additional advice for survey participants about the aim of the study etc. was inserted. Before sending the data back to ISI for analysis, the answers inserted by the participants were translated into English by the project partners.

After conducting the interviews and a preliminary analysis of the data, results from the interviews were discussed several times to validate the conclusions drawn. The first group discussions took place at the fifth project meeting, in Freiburg, in September 2009, after about half of the interviews had been conducted. After completion of the interview studies, the
results were presented and discussed at meetings of the two German lift associations (VFA-Interlift, VDMA). Additionally, the results were discussed in a telephone conference organised by ELA, including five ELA representatives. These discussions contributed to fact verification, in case of contradictory information resulting from interviews, as well as to adding additional facets to the data. In sum, a homogeneous picture could be formed based on the data gathered and this will be summarised below.

6.5.4. Identification of relevant barriers

*General market characterisation regarding energy efficiency*

Interview partners agreed that the energy efficiency of lifts and escalators are increasingly being discussed. While some state that the topic has already almost reached its peak and is expected to lose significance in the future, others assume that the discussion has just started and expect it to be continued and deepened.

These different perceptions of the current state of the discussion can be explained by several trends. Those who already see the debate losing momentum claim that it was initiated about two years ago by manufacturers of installations and specialised consultants. Main issues were technological advancement and how energy consumption could be measured in a standardised way, but also the integration of energy efficiency into marketing strategies to promote products. However, the discussion is just about to reach the customers, i.e. architects and construction engineers, construction companies as well as investors. Operators, owners and, to some degree, also users are expected to join in sooner or later. Thus, the knowledge and awareness of energy efficiency of these stakeholders is assumed to be still low, while manufacturers' competence is rising.

Interview partners also state differences between European countries, i.e. the newer and older members of the European Union. Interview partners from German-speaking countries also emphasised the impact of the German guideline VDI4707 [6]; on the one hand, it provided a first basis for standardised measurement of electricity consumption, calculation of energy demand and labelling, on the other hand – at least from their point of view – it has contributed towards intensifying the discussion about energy issues of installation also in other countries.

The discussion is also observed to be more intensive for lifts than for escalators. Moreover, awareness is reported to be higher for grand-scale installations, e.g. airports, and to be especially low for small-scale residential buildings.

A topic that is heavily debated in this context is the economic efficiency of energy-efficient technology. Few examples of measures are given where economic pay-off is not doubted by the experts surveyed, e.g. turning off the light if the car is not in use. For other measures, e.g. investing in the drive system, opinions were diverse and heterogeneous – even among experts from manufacturing and notified bodies. Experts also gave contradictory prices for technological measures, which, of course, led to differing opinions regarding economic efficiency.
This indicates that expertise is limited, due to the complexity of the products, the low degree of comparability between installations and due to missing data and standards for measuring energy consumption, as well as rapid technological advances in some areas. However, no clear advice could be derived regarding measures to overcome the problem of missing data. On the one hand, doubts were repeatedly expressed about the possibility of giving standardised advice on how to achieve energy efficiency and economic efficiency for an individual installation. On the other hand, it is claimed that exactly this kind of information is needed. Additionally, some interview partners emphasised the importance of drawing more attention to balancing financial investments and possible savings.

Regarding retrofits, doubts were expressed whether it makes sense to modernise an installation only to enhance energy efficiency. In general, some experts pointed to the long life-cycles of installations which offer a long time range for investments to become efficient. Moreover, economic efficiency was perceived to be more easily realised for large-scale installations than for small-scale ones.

We further asked experts to elaborate on the decisive aspects for customers when choosing an installation. Price was pointed out by the majority as the central aspect. The amount of investment is especially influential for the buying decision if the customer is not the final owner and/or user of the installation, i.e. if a building is erected by a general contractor. Life-cycle costs – and therefore costs for energy consumption – were hardly mentioned as a decisive criterion.

Further aspects seen as influential in the choice of a model were maintenance, services offered by the manufacturing company and – to a lesser degree – running speed, comfort, interior and aesthetics as well as running smoothness. Moreover, the interview partners acknowledged that the intended usage, e.g. capacity, aspects related to accessibility, also influences the choice of equipment. However, several experts complained that the requirements of equipment are often not thoroughly analysed, thus leading to misspecifications. From an architectural point of view, the amount of space needed for the lift shaft was also seen as an important aspect. Surprisingly, safety was only mentioned twice; however, we assume that this is due to high safety standards already implemented.

We also asked if existing legislation, regulations or norms impede energy efficiency, thereby creating a barrier. However, most respondents confirmed that this is not the case. On the contrary, experts pointed out that lifts and escalators suffer from a lack of regulation, e.g. as they are not included in the EPBD and their national implementations. Legal uncertainty was repeatedly discussed in connection with regeneration – an issue that will be further discussed below.

Regarding differences between lifts and escalators, the statements of the experts confirm our analysis. As lifts are more complex, they yield more potential for improvement in terms of energy efficiency. Moreover, escalator models from different manufacturers are technologically similar, i.e. competition in the market is mainly about prices.
We also asked which stakeholder influences the most when choosing the technology for a certain installation. However, the answers emphasised a large range of influential stakeholders. In general, the manufacturer and its sales department have a strong influence regarding types of installations offered to a client. On the clients’ side, there may be a specialised consultant making a choice – however, this is regarded as an exception. Otherwise, it depends on the individual constellation, there may be an architect or construction engineer involved, sometimes the operator or owner of the building becomes involved; in the case of new buildings, the technical equipment including the lift is chosen by the responsible general contractor. However, situations vary and, therefore, measures to overcome the identified barriers have to address different kinds of target groups.

Results from the interviews on barriers

A summary of the results regarding barriers is given in Figure 7-2.
Figure 7-2. Overview of ratings of barriers to energy efficiency for lifts and escalators. Highest ratings are marked in red, lowest in green.

The graphs show the frequencies of item ratings. Respondents were asked to assess whether a barrier from our list is true 1) never or only in very few cases, 2) in some cases 3) in most cases. An additional category is introduced which corresponds to the number of respondents who did
not rate an item. Reasons for non-rating were various, e.g. respondents stating they did not have any knowledge on a certain topic or not providing clear answers. The barriers that were rated to be most relevant are coloured red, those least important, green. These highlights provide a homogeneous picture: barriers to energy efficiency – from the point of view of the experts surveyed – are mainly due to lack of information and transparency regarding energy consumption of equipment (cf. operators not monitoring energy costs, decision-makers not aware of energy consumption) and split incentive issues in relation to bounded rationality (cf. energy costs not paid by decision-maker, investment more important than life-cycle costs, components would be more efficient if operators had more transparency). Risks and uncertainties play a minor role, as shown by the green highlights, while capital issues received middle-range ratings. However, the items on lack of capital in new installations and retrofit were also those which are based on the lowest number of ratings, i.e. nine and ten respondents respectively did not provide a rating.

**Information and transaction costs**

In general, ratings indicate that, in the experience of the experts interviewed, it is not common that operators of lifts or escalators regularly monitor the energy consumption of their equipment. In most cases, no technical appliances are installed that would enable regular monitoring; thus the energy consumption of lifts and escalators cannot be separated from other equipment, e.g. lighting, automatic doors.

This is seen as related to the fact that individuals choosing equipment as well as operators and users are not aware of the energy consumption of the equipment. Due to a low degree of awareness, no measurement devices are installed – and due to missing data, individuals do not become aware of potentials to increase the energy efficiency of their installations.

Information on energy-efficient technology is, however, not regarded as especially difficult to obtain. Main sources of information that were identified by the respondents are, however, the manufacturers and their sales representatives. Thus neutral sources of information are missing or insufficiently known. The experts emphasised that the knowledge provided by sales representatives is usually restricted to the technology used by their company and that energy-efficient technology is sometimes too new to be fully understood, even by company representatives. Additionally, clients are seen as usually having little knowledge themselves, and thus do not inquire about relevant data.

**Split incentives and bounded rationality**

Split incentives between general contractors, owners of installations as well as those paying for the energy consumption of installations are also seen as a barrier hindering energy efficiency for lifts and escalators. The costs of energy consumption are usually paid by inhabitants – in the residential sector – who are not necessarily the owner of the building. Additionally, buildings including a lift or escalator are often erected by a general contractor for

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5 For example, in Germany, neutral information may be obtained from notified bodies.
whom the energy consumption of the lift or escalator installed does not matter at all. Moreover, end-users are usually not aware of the costs produced by energy consumption of these installations. Thus, life-cycle costs play a minor role when an installation is chosen. This may also be the case for retrofits, due to the low levels of awareness and due to the high number of stakeholders involved. This situation already implied in our analyses above was confirmed by the expert interviews.

We also asked whether lack of time during the decision-making process might be a barrier to energy efficiency. However, most participants denied such a relation in most cases. One exception was pointed out: lack of time may play a role if the current equipment breaks down and needs to be replaced quickly.

**Capital**

Lack of capital is not seen as a major barrier to energy efficiency; based on the responses of the experts surveyed, this is true for new installations as well as retrofits. However, the willingness to invest more money in energy-efficient technology may be a problem, especially in case of split incentives.

In addition, some experts stated that energy-efficient technology is not necessarily more expensive than less energy-efficient technology and that prices for new technologies are decreasing.

We explicitly asked about budgeting laws or regulations that might hinder investment in energy-efficient technology for public buildings; the experts did not rate this as a major problem.

**Risks and uncertainties**

Risks and uncertainties related to energy-efficient technology in lifts and escalators are not seen as major barriers. Especially risks related to the reliability of energy-efficient technology received low ratings. The technology is not seen as being vulnerable to disruption of operation, or increasing the need for repair and maintenance, or increasing training requirements for technical personnel.

Changing energy prices were not seen to affect economic profitability and thereby creating uncertainty; as outlined above, energy-efficient technology is generally not seen as being connected with higher investment. Moreover, energy prices are expected to rise.

We also asked about cases in which expectations for energy savings could not be fulfilled. Experts pointed out that this might happen, e.g. in cases where very old installations are retrofitted and additional equipment is needed to comply with current safety standards. However, the majority acknowledged that this is not a significant problem.

Moreover, energy efficiency is not seen as competing against safety and comfort.
Further barriers

We asked respondents whether they had further barriers in mind that were not part of our list and we also screened interview notes for further barriers. Several experts stated that they did not know about further barriers.

However, several issues were raised. It was stated that data and standards for measuring energy consumption are lacking – a fact which may also be seen as a barrier to energy efficiency. The low level of awareness was addressed again, as well as the low level of knowledge and independent professional consultancy.

6.5.5. Conclusions

The main conclusions to be drawn from our study on barriers can be summarised as follows. Major barriers to the diffusion of energy-efficient technologies are due to a lack of energy consumption monitoring of equipment and a lack of awareness, as well as knowledge, about energy-efficient technology. This problem is exacerbated by the fact that the main information source is the manufacturers (and their sales departments), however, their knowledge of energy-efficient technology may also be limited. Thus, installations are usually chosen without a (comprehensive) assessment of their energy consumption and without considering life-cycle approaches.

Moreover, problems arising from split incentives contribute to impeding the diffusion of energy-efficient technology; an installation is often not chosen by the later operator/user of the installation. This problem is intensified by the following facts: maintenance and energy costs are usually divided between several occupants of a building and an average energy consumption of 3 to 10% of the whole energy consumption of a building may be too low to attract attention. In general, awareness of energy-efficient technology is keen among manufacturers of lifts and escalators, but the discussion has not reached other stakeholders.

Other barriers, e.g. lack of time or capital, reliability of technology, or legislation, only play minor roles. However, price is crucial, although the lack of capital is not a major problem. This has to be seen in relation to the split incentive problem already addressed. Moreover, the economic efficiency of energy-efficient technology is a topic that is being hotly debated and that suffers from misunderstandings and lack of reliable data.
7.2 Strategies and measures

Recommendations for lifts

The following sections give recommendations for measures which aim at transforming the European lift market towards more energy efficiency. These conclusions are based on the material accumulated in prior chapters of this report.

Standardisation of measurement and calculation

Today, the energy consumption of a single installation is usually unknown to its owner as well as to the maintenance company and the manufacturers. Manufacturers have recently started to invest time and energy in providing measurement data for their equipment. However, a harmonised measuring and calculation methodology has not been implemented so far, either at European or at international level. Such a standard would include a definition of how and what is measured, how annual consumption values are calculated and how different solutions can be compared.

Otherwise it is not possible to compare different models or installations or make informed decisions about equipment. Thus this gap needs to be closed as soon as possible, e.g. accelerating the ongoing international standardisation efforts. First concepts of how to measure electricity/energy consumption and calculate energy demand of lifts have been brought forward, e.g. by ISO 25745 [7], the German VDI4707 [6], the Swiss SIA 380-4 [8] or by the E4 project [8].

However, defining a transparent standard for measuring energy consumption is only the first step in reaching comparability of different models of installations. In addition, a scheme needs to be established that allows for simple comparisons between models, e.g. focusing on one or two aggregate values or labels for each model (one for running and one for standby, for example). It would probably be helpful if lifts were grouped into categories, e.g. depending on payload, cabin size, travelling distance, intended usage. Development of such a classification goes beyond the scope of this project, however, from our point of view, this is the next step.

In addition, more detailed analysis of costs and benefits from certain measures aiming at energy efficiency could be helpful to identify the measures that are both energy-efficient and economically viable. Such an analysis could address several of the knowledge gaps which became obvious during our study. The results could contribute to extending and further elaborating the list of features provided by [10].

Regulatory approaches and incentives

Lifts should be included in the relevant framework of regulation and legislation. Up to now, lifts are neither included in building directives, e.g. EPBD, nor in electric equipment directives, e.g. ErP. Many subsidised programs, e.g. to increase the energy efficiency of buildings, draw on these directives (or their respective national implementations) to define eligible projects. Thus, lifts would become part of these programs as well.
Raising awareness

Setting a standard for measuring energy consumption, calculation of the energy demand and complementary legislation would already contribute to raise awareness about energy efficiency to some extent. However, higher levels of awareness are necessary – especially on the customer’s side – to guarantee that energy efficiency of lifts is optimised. Although developing a communication strategy for an awareness campaign is beyond the scope of this report, some advice will be given regarding target groups and options to be considered.

Main target groups for awareness-raising measures are the stakeholders involved in the planning and construction of buildings, i.e. those who decide if new equipment is installed, as well as those who later use or operate an installation, i.e. those paying for energy consumption and deciding on retrofits. As it was already discussed above, this includes several groups of stakeholders.

One way of raising awareness in several target groups is labelling equipment in a comparable and comprehensive way, as has been done for other electrical equipment, e.g. freezers and refrigerators. However, given the high number of types of lifts, the development of a comprehensive labelling system may take some time. VDI 4707 provides a labelling example. In the meantime, other measures to raise awareness should be put in practice. This is also important as labelling addresses only new equipment and does not include existing installations. However, due to the long life-time of lifts, it is necessary that measures for market transformation address existing installations as well.

Figure 7-3. Energy certificate for a lift according to VDI 4707 Part 1
The first steps to raise awareness are already part of the E4 project, e.g. developing dissemination material providing information for different kinds of target groups and organising workshops with information on this topic. These activities need to be extended after the end of the project, e.g. by national energy agencies or notified bodies. Main target groups should be architects and construction engineers, construction companies that act as general contractors, as well as building operators, and administrators. While the first two groups are more important in the process of installing new equipment, the last one is relevant in case of retrofits and modernisation. However, in order to advise all these groups on energy-efficient equipment, easily accessible and comprehensive information material is required – a topic that will be further discussed in the next section.

**Enhancing knowledge**

One of the general experiences of lift experts is that most customers have little knowledge of lifts. Furthermore, specialised consultants are only involved in a minority of projects. Thus, raising awareness is not enough to enhance energy efficiency: even if decision-makers were aware of energy efficiency, they would not know how to achieve this goal. Here again, standardised measurement turns out to be the key to energy efficiency. Without comparable data for different models and types of lifts, customers are not in a position to make an informed decision.

Additionally, based on this, relevant information has to be accessible to customers, e.g. via Internet or brochures. This includes, for example, checklists of energy-efficient components which may be consulted for retrofits. Additionally, it should contain references on how further information can be obtained or whom to ask if professional consultancy is needed. It is important to keep in mind that this information has to be directed at different target groups: general contractors, individuals involved in the planning process of buildings as well as operators and administrators of buildings and building owners. Thus, several channels have to be used to communicate about information sources once they are established.

**Modernisation of existing stock**

Lifts have a long life-cycle: they can be operated for up to 15 to 30 years without major modernisation. Thus, if energy efficiency in this field is supposed to increase significantly within a short period of time, it is necessary to modernise the existing stock.

If it is intended to renew well-working components it is necessary to take into account i) the energy efficiency potential; ii) the costs, i.e. the economic efficiency of the measure; and iii) the general sustainability, including for example the energy consumed for recycling the old component, producing and installing the new one etc. Therefore, making reasonable decisions in this regard is extremely difficult and contains several unknowns. It is not possible to give general recommendations based on the current state of knowledge or the data accumulated in this project. There are some basic measures which contribute to energy efficiency, e.g. turning off the light when nobody is inside the car (see [10], for more detailed information). However, detailed studies are missing that could generate further recommendations on this issue.
In addition, as lifts are individually engineered products and each installation has its own characteristics and conditions, it is extremely difficult to develop general recommendations at all. As a next step, we therefore recommend collecting case-study research as a basis for evaluating reasonable technical measures.

**Assessing life time costs**

The lift installations that were audited during the monitoring campaign of the E4 project and the data provided by the different player representations show that lifts and escalators are quite heterogeneous systems whose energy consumption strongly depends on the use of the lift. Highly frequented lifts have higher operating costs due to the energy consumption than lifts that run less frequently. Conversely, the energy consumption of lifts that are used less often is dominated by standby consumption. However, the optimal components contributing to energy efficiency in running or standby modes are not always identical, thus creating trade-off problems for customers.

Any decision-maker is in the difficult position of having to assess his or her special case and to predict future usage of the lift. Assessing life time or life-cycle costs can contribute towards identifying relevant factors to take a decision that is efficient in economic and in energy terms.

**Further topics**

This section addresses further topics that are of relevance if the energy efficiency of lifts is to be optimised.

**Regeneration**

Elevators do not only consume energy, they may also generate electricity when they are going up or down, depending on the loading condition. This is advantageous for several reasons: a) this electricity may be used by other devices, b) the energy created when the elevator is going down can be turned into electricity and fed to the grid, meaning less effort is needed for cooling – thus even less energy is consumed.

From a technical point of view, today it is neither complicated nor expensive to include regeneration in the lift system. It is a useful feature to increase energy efficiency for many installations. However, precise knowledge about regeneration is scarce, even among manufacturers of lifts. Price ranges discussed in this context vary greatly and insecurity is high regarding legislation on this topic. This is related to the question of whether it is legal to feed electricity into the grid which is not consumed by other electrical devices immediately. This topic needs clarification.

**Interface building-installation to be optimised**

Further potentials to save energy in the context of lifts can be found at the interface between lift and building. First of all, lift shafts usually contain shaft vents which are necessary for ventilation and in case of fire. However, they also act as connections to the outside, i.e. letting
in hot air in the summer and cold air in the winter. Intelligent solutions to prevent this are available on the market, but are not installed very frequently.

In general, the interface building-lift is often not analysed from the point of view of energy efficiency, as lifts are not part of the EPBD and similar regulations. Thus, information campaigns about the energy efficiency of lifts should not solely concentrate on the lift system itself, but also on its integration in the building.

Quality of installation

Lifts are individually engineered installations. Therefore, similar models may consume different amounts of energy, due to the specific conditions in the building where they are installed. However, the quality of work during installation also greatly contributes to energy efficiency – and is crucial for realising potentials for increasing energy efficiency. Dispan [1] notes that installation quality has been decreasing due to outsourcing, time and cost pressure. However, if lifts do not run smoothly due to bad installation quality, a vast amount of energy is wasted.

Accessibility and alternatives to lifts

The European population is ageing, awareness of accessibility issues is rising and people are constantly expecting more comfort in their everyday environment. Thus the demand for vertical transportation is expected to grow in the coming years. Lifts are an important mean of enabling everyone to have access to the built environment (cp. Guide to application of the lift directive 95/16/EC, §99 [11]).

However, non-necessary installation and use of lifts is an issue that should also be considered when energy efficiency for lifts is being discussed. For instance, in hotels or office buildings, staircases are sometimes hard to find and less attractive to use; thus everybody takes the lift, even healthy people. However, if staircases were as obviously indicated as the lift it may sometimes be possible to reduce a bank of lifts from three to two etc. – which may reduce energy consumed by vertical transportation without limiting accessibility. Campaigns about the energy efficiency of lifts should also address this issue – without implying a decrease in accessibility.

Recommendations for escalators

Recommendations for escalators are similar to those for lifts. However, as escalators are simpler and less diverse systems than lifts, from a technical point of view, and as they are usually bought by a different, more professional and cost-conscious customer group, they should be more easily achieved. First of all, as for lifts, a standard for measuring energy consumption is needed to provide a baseline for comparison. Second, escalators should also become subject to relevant regulation regarding energy efficiency. Third, a labelling system could help raise awareness and provide a basis for decision-making.
7.2.1 Conclusions

Thus, based on our analyses, we come to the following conclusions regarding a strategy for market transformation in the lift and escalator market. First of all, a European standard for measuring the energy consumption and calculation of energy demand of lifts and escalators is needed. This kind of standard is the basis for comparisons between more and less energy-efficient technology and the existence of a standard will already contribute to raise some awareness. Second, lifts and escalators should become subject to legislation and regulation concerned with the energy efficiency of buildings, namely, they should become part of the EPBD. Third, campaigns and material directing attention to the issue of energy efficiency of lifts and escalators is needed. This third conclusion is to be combined with the fourth, providing easily accessible and understandable information for buyers of lifts and escalators to support decision-making processes. The most important groups to be addressed in these campaigns are, on the one hand, those involved in decision-making of installations for new buildings, i.e. general contractors, architects and construction engineers, on the other hand, those involved in maintaining lift and escalators services in buildings, building administrators and operators.

These conclusions are based on the results of our analyses which indicate that energy-efficient technology for lifts and escalators is being offered in the market. The main barriers to the market penetration of these technologies are low levels of awareness and knowledge about these technologies as well as split incentives.

The scope of the present study is obviously limited and results give a simplified picture of the European lift and escalator market. The EU consists of 27 heterogeneous countries, in regard to size, population density, demographic structures, as well as economic development – these and other factors have strong implications for the lift and escalator market. Thus, for example, even if lack of capital was not identified as a major barrier to energy efficiency at a general level, it may be of high relevance in some regions of the EU.

Making lifts and escalators more energy-efficient is even more important in an international dimension: internationally, the population is growing and therefore cities are also growing extensively – thus the importance of vertical transportation is constantly rising, posing a constant challenge to energy efficiency.

7.3 Guidelines for New Lift Installations and Retrofitting

Lifts and escalators are individually engineered systems instead of off-the-shelf products or standardised products. Elevators in particular are very heterogeneous systems: they can be standard systems, more individualised systems based on standard components or, in special applications, individually tailored installations where individual components and equipment are used.

This document provides advice on options to increase energy efficiency of new and existing installations. However, recommending standard measures is difficult, if not impossible, due to the large heterogeneity of installations and their usage. Thus, in order to increase energy efficiency, the system as a whole has to be evaluated, taking into account both the energy
performance of single components and their interaction, as well as further conditions, starting with frequency of use. There are only few features that are advisable in general.

Therefore, a list is provided, identifying features that are possibly helpful in reducing energy consumption. It has been compiled from the project findings, from discussions with experts and stakeholders (cf. [11]), and from relevant literature (e.g. Nipkow 2005 [12], Guideline VDI 4707 [6], Draft International Standard ISO/DIS 25745-1[7], Clausnitzer et al. 2009 [13], Barney 2007 [14], Beier 2009 [15]). It is supposed to be used as a checklist for planning new installations or increasing the energy efficiency of existing installations. The checklist claims to be neither conclusive nor exhaustive, nor does it claim general energy efficiency or cost-effectiveness of the measures.

In the following, several lists with features that can possibly help increase energy efficiency are provided. These lists are either relevant for lifts, escalators or both systems. Each feature is briefly discussed and commented. Then a recommendation for an energy-efficient solution is given, with an indication under which conditions this feature is especially relevant.

7.3.1 Common features for energy-efficient installations

Energy efficiency of installations can be best obtained if energy efficiency is considered from the very beginning of the planning process (see also [16], pp. 60–63). Awareness and knowledge are crucial prerequisites for the appropriate design, selection, operation and maintenance of energy-efficient equipment.

Table 7-3 provides a list of aspects that are not directly linked to the energy performance of individual installations, but that are in general an important contribution to energy efficiency.

Table 7-3. Energy efficiency: Awareness and knowledge

<table>
<thead>
<tr>
<th>Awareness &amp; knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Educate sales and design staff</td>
</tr>
<tr>
<td>The role of a sales person is a very important one when offering and selling technology. During an expert consultation (cf. [9]) it was repeatedly stated that sales personnel are often not sufficiently aware of the consequences of certain technological choices or available technological possibilities.</td>
</tr>
<tr>
<td><strong>Recommendation:</strong> especially manufacturing companies (but not limited to them) should sensitise their sales and design staff to issues of energy efficiency.</td>
</tr>
<tr>
<td>2 Educate installation and maintenance staff concerning energy efficiency</td>
</tr>
<tr>
<td>Next to assuring and verifying comfort and safety during maintenance, maintenance personnel should also be sensitised to energy issues. Problems of increasing energy demand can sometimes be found by simple inspection. In addition, maintenance staff is usually closest to the final customer or operator, thus often giving the impetus for taking retrofit measures to increase, among others, energy efficiency.</td>
</tr>
<tr>
<td>The role of the staff performing the installation is also very important, especially for lifts. This issue is further discussed in Table 7-7.</td>
</tr>
<tr>
<td><strong>Recommendation:</strong> sensitise installation and maintenance staff.</td>
</tr>
</tbody>
</table>
3  **Check benefits of including third party support**

Often offers for new installations or retrofit measures primarily come from the service company or the company known to the customer from earlier transactions. Thus the scope of offers may be limited to the production program of this company (cf. [9]). Checking offers from other companies could be helpful by having a baseline for comparison. Engaging an independent expert lift consultant may help extend the scope of ideas and they can evaluate different available solutions.

**Recommendation:** check whether to ask more than one company for an offer and whether to include a third party expert.

When looking at specific installations, a first step in determining the best solution in terms of energy efficiency is to check, analyse and discuss the actual requirements and expectations. Table 7-4 provides a list of aspects that contribute to choosing energy efficiency solutions in this specification phase.

**Table 7-4. Energy efficiency: Specification**

<table>
<thead>
<tr>
<th></th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4</strong></td>
<td><strong>Check necessity of lift or escalator installation</strong></td>
</tr>
<tr>
<td></td>
<td>The purpose of elevators and escalators is to provide accessibility to all. Any building with two levels or more may need elevators and/or escalators for accessibility reasons.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> in a building where elevators or escalators already exist, it should be discussed first whether already existing installations could be modified or extended to satisfy the transportation capacity while ensuring acceptable waiting time, before adding further installations.</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> new installations and retrofits located in buildings where more than one vertical transportation systems are found.</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td><strong>Check location and number of installations</strong></td>
</tr>
<tr>
<td></td>
<td>Selecting the appropriate location for lifts or escalators can increase comfort and ease for the users and it can help reduce the number of required installations.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> in buildings where several lift installations are planned, different arrangements of lifts or escalators can be considered. Reducing the number of installations by one can mean reducing overall consumption, but it has to be addressed together with other aspects, such as building design, accessibility, traffic handling capacity, acceptable waiting time, safety, and so on. The location of the lift and escalator should also be analysed, together with the location of staircases. Easily accessible and attractively designed staircases may contribute to reducing energy consumption due to a lower frequency of use of the lift or elevator.</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> especially relevant for new installations.</td>
</tr>
</tbody>
</table>

**6.5.6. Specific features for energy-efficient lifts**

The previous section dealt with aspects that are relevant both for lifts and escalators. In this section, features that are specifically relevant for lifts are discussed. The roles of specification, awareness and knowledge have already been discussed in the previous section. For lifts, the equipment selection process is further examined, both for the drive system and ancillary equipment. Then issues concerning the installation process are discussed. Finally, measures taken during operation are discussed (cf. Figure 7-4).
Aspects of drive systems are discussed in Table 7-5, aspects concerning ancillary equipment are treated in Table 7-6.

Table 7-5. Energy efficiency: Lift drive system

<table>
<thead>
<tr>
<th>6</th>
<th>Check dimensioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>The dimension of the car, the load and the speed determine among others the requirements for the drive system.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> to determine the number of lifts, their relevant car size and speed, the specific needs for accessibility and emergency requirements in combination with a careful analysis of traffic handling and acceptable waiting times has to be carried out. Some exemplary recommendations are given by Nipkow [12], p. 37.</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> especially relevant for new installations, but also for (larger) retrofits.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7</th>
<th>Check necessity of additional non-lift comfort equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>For reasons of providing information, comfort and design, lifts are sometimes equipped with additional appliances such as permanently running TV screens, music, and other equipment. Such equipment can have a significant impact on energy consumption, especially when it runs permanently.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> check the necessity, consumption patterns/energy efficiency, and frequency of use of this additional equipment to reduce consumption.</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> new installations and retrofits.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8</th>
<th>Check for appropriate drive technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>As described in Chapter 2, different principles exist to move lift cars. The consumption of drive technology can have a very large impact on energy consumption, especially for installations that are running very often.</td>
<td></td>
</tr>
<tr>
<td>Conventional hydraulic lifts have a higher running consumption than conventional traction lifts under comparable conditions (Sachs [2], p. 2, Nipkow [12], p. 7, Brzezina [17]. Nipkow [12], p. 35 or ISO Draft International Standard ISO/DIS 25745-1 [7], p. 12). Note that modern hydraulic concepts can provide similar efficiencies to modern traction lifts.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendations:</strong> it should be checked which technology is the best choice in terms of energy efficiency in a given case.</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> choosing energy-efficient drive technology is more relevant in the case of new installations and retrofits with medium or high numbers of trips. In case of low frequency of usage (low number of trips), more attention should first be paid to standby consumption.</td>
<td></td>
</tr>
</tbody>
</table>
### Check for adequate gearing & roping of the system

A gear is used to transform the torque-speed ratio of a motor. In traction lifts, this gear is found between the motor and the traction wheel. A gear has moving parts, causing friction and thus causing energy losses; the overall amount of losses depends among others on the type of gearing used. Using a high efficiency gear or removing a gear can thus increase energy efficiency. Roping, that is, the configuration of how car and counterweight are connected to the motor, has a function similar to gearing, as it can help reduce the required torque of the motor. Modern traction systems are nowadays offered as gearless systems, using high torque motors to move the car.

**Recommendation:** using the right combination of gearing, roping and pulleys to achieve optimal energy efficiency and functionality is a complex task. Nipkow [12] p. 38 proposes using planetary gears or gearless systems to increase energy efficiency. Discussing different solutions should help increase energy efficiency.

**Relevance:** especially relevant for new installations but also for (larger) retrofits.

### Check system architecture

Ropes or hydraulic cylinders can be connected to the car in different places. They are either connected in a central position (in the middle of the car) or laterally.

**Recommendation:** according to Clausnitzer et al. [13], p. 44 and Nipkow [12], p. 38, using a central connecting point reduces friction and thus reduces energy consumption.

**Relevance:** especially relevant for new installations but also for (larger) retrofits.

### Check usage of high efficiency & properly sized motor

The efficiency of the motor driving a lift system is a key component for energy consumption. The motor efficiency means the ratio between electrical input power and mechanical output power of the shaft. The higher the efficiency rating, the lower the losses during operation. The efficiency rating outside the nominal operating point is variable (see chapter 3). Over-dimensioning motors can, however, provide additional thermal operating safety according to Nipkow [12], p. 25.

**Recommendation:** the chosen motors should have a high efficiency both in terms of full load efficiency but also in terms of part-load efficiency.

**Relevance:** especially relevant for new installations but also for (larger) retrofits.
<table>
<thead>
<tr>
<th>12</th>
<th><strong>Check benefits of using regenerative drives</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>In conventional traction lifts, braking energy is dissipated by a braking resistor. A regenerative system allows energy to be recovered and fed back either into the building or into the electrical grid, depending on the configuration and local regulations (see Chapter 3). Nipkow [12], p. 35, estimates that the degree of energy recovery (as the relation of recovered energy to overall energy demand for travelling up and down) for small lifts (630 kg, 1.6 m/s) is below 30% while for large installations (2,200 kg, 2.5 m/s), it can be up to 40%. Recovery is possible during a period of stable running, thus decreasing the recovery potential for lifts with shorter shafts.</td>
<td></td>
</tr>
<tr>
<td>In conventional hydraulic systems, braking energy from a descending car is dissipated via a throttling valve. Recent hydraulic solutions allow, for example, accumulating pressure in a storage vessel due to a descending car. This pressure can reduce the energy consumption to hoist the car during the next usage.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> especially for often running, large installations; using a drive system with regenerative capabilities is a possibility to reduce energy consumption.</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> especially relevant for new installations but also for (larger) retrofits.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13</th>
<th><strong>Check usage of a frequency converter with automatic standby function</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern lift installations are often equipped with frequency converters. These units allow for a controlled start and operation of motors, thus providing controlled movement of the car and increasing comfort. Furthermore, they reduce slip losses during motor start-up. (see Chapter 3)</td>
<td></td>
</tr>
<tr>
<td>The use of frequency converters can lead to additional standby consumption. Modern units provide an auto standby function, this means that internal components automatically switch to reduced or no consumption when not needed.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> using frequency converters without standby can help decrease standby energy consumption</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> especially relevant for new installations but also for (larger) retrofits.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>14</th>
<th><strong>Check usage and optimisation of counter-balancing</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A counter-balance reduces the load the lift drive system has to move when the lift is running. This allows the use of smaller motors and less energy is required to operate the system.</td>
<td></td>
</tr>
<tr>
<td>Often a counter-balance has the same mass as a lift car plus half of the nominal load. Therefore, it requires less energy when the lift is carrying half of the payload. In practice, lifts often travel empty to their destination floors, or they transport only a small number of passengers, thus the actual average load is below 50%. Adjusting the mass of the counter-weight can thus be an option to reduce the average motor load and to reduce energy requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> consider using a counter-weight to reduce the load the drive system has to lift and optimise it in accordance with the actual usage requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>Relevance:</strong> especially relevant for new installations but also for (larger) retrofits.</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th></th>
<th>Reducing the mass of the car</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In systems without a counter-weight, the motor has to lift both the weight of the cabin as well as the additional payload. Therefore, the reduction in cabin weight, by using for example light weight materials, can increase energy efficiency, provided that both stability and safety remain unaffected. In addition, a reduced mass can decrease energy demand for acceleration and deceleration, also in systems with a counter-weight.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> check benefits of using a car with reduced mass.</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> especially relevant for new installations and (larger) retrofits that are often used and that do not have a counter-weight.</td>
</tr>
</tbody>
</table>

Table 7-6. Energy efficiency: Lift auxiliary equipment |

<table>
<thead>
<tr>
<th></th>
<th>Design of ancillary lift equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td><strong>Use energy-efficient lighting &amp; appropriate surface material</strong></td>
</tr>
<tr>
<td></td>
<td>Lighting can be one of the most important energy consumers in a lift, especially when it is burning 24 hours a day. Reducing the required lighting power is thus an important option to increase energy efficiency. Modern lighting technology like compact fluorescent lamps or LED technology can reduce energy consumption (see Chapter 3). Avoiding dark surface materials and textures in the car interior can also contribute to reducing the energy consumption required by lighting.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> the most energy-efficient solution for permanently running lighting is to use LED lighting. Using energy-efficient lighting and switching it off is a complementary solution (see also item 22).</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> very relevant for new installations and also for minor retrofits. A replacement of the lighting equipment can also be easily accomplished in existing installations. This measure is estimated to be very cost-effective.</td>
</tr>
<tr>
<td>17</td>
<td><strong>Avoid stalled motor door operator</strong></td>
</tr>
<tr>
<td></td>
<td>Arbitrarily opening doors are a safety hazard in lifts. Therefore, car doors have to remain shut while the car is moving, for safety reasons. Some locking mechanisms rely on a stalled motor to keep doors closed, also when the car is not in use [13]. Therefore, these systems require energy permanently.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> using door-locking mechanisms that do not permanently require energy for the locking mechanism when the lift is not in use.</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> this is both relevant for new installations and (smaller) retrofits.</td>
</tr>
<tr>
<td>18</td>
<td><strong>Use energy-efficient transformer and power supply</strong></td>
</tr>
<tr>
<td></td>
<td>Some lift circuits require low voltage energy that is supplied by a transformer or power supply.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> the efficiency of this transformer or power supply during operation should be selected as high as possible, while standby consumption should be low (cp. [12], p. 34).</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> this is both relevant for new installations and (smaller) retrofits.</td>
</tr>
<tr>
<td>19</td>
<td><strong>Use energy-efficient components for all other components and equipment</strong></td>
</tr>
<tr>
<td></td>
<td>An installation includes further equipment, such as ventilation systems, operating panels, buttons, intercoms, etc. that are not discussed in detail in this document. However, it may be worthwhile to check the energy efficiency of these components as well.</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> for ventilation, high-efficiency motors should be used. Operating panels, buttons and other auxiliary equipment should also be selected to be as energy-efficient as possible.</td>
</tr>
</tbody>
</table>
Relevance: this is both relevant for new installations and retrofits.

When energy-efficient equipment is selected, the equipment has to be properly installed to make use of its full energy-saving potential. Table 7-7 discusses the role of installation quality and the lift-building interface.

Table 7-7. Energy efficiency: Lift installation

<table>
<thead>
<tr>
<th>Installation</th>
</tr>
</thead>
</table>
| **20** | Ensure installation quality
| A factor influencing the energy consumption of a lift is the quality of the installation. A bad installation quality often has a negative impact on energy consumption. If guiding rails are for example poorly installed, additional friction is induced, thus more energy is needed to move the car.  
**Recommendation:** the installation of a system should be accomplished by personnel with the appropriate qualifications. Otherwise, energy losses are likely to occur due to bad installation quality, sometimes even negating the effects of the selected energy-efficient equipment.  
**Relevance:** all lift installations.  
| **21** | Interface lift and building: shaft ventilation, smoke clearance, shaft insulation
| Ventilation of the lift shaft has two purposes: first, to provide fresh air to the lift shaft and the cabin, second to remove smoke from the building in case of fire. Ventilation is in the simplest case, accomplished by a permanently opened hole in the building shell. Therefore, depending on the configuration, this opening can lead to uncontrolled thermal losses.  
As the shaft and its features are a part of the building, lift companies often do not feel responsible for this issue. However, as this is induced by lift installations, building planners and constructors do not feel responsible either. As this can lead to considerable losses, this aspect also needs to be taken into account. Furthermore, shaft walls are heat-conducting parts of the building that are often forgotten when the building is insulated [13].  
**Recommendation:** the lift system needs to be closely monitored also regarding its integration into the building as a whole. Uncontrolled ventilation and losses by heat conduction should be avoided.  
**Relevance:** all lift installations.  

Next to their energy efficiency, the running time and usage of these components are very important factors for overall energy demand. A list of different operational and organisational measures to reduce energy consumption can be found in Table 7-8.
### Table 7-8. Energy efficiency: Lift operation

<table>
<thead>
<tr>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
</tr>
</tbody>
</table>
|     | Some light sources such as modern LEDs can be dimmed and switched off without reducing their life time (see Chapter 3). Provided that such light sources are installed in a lift, switching off the car lights when a lift is not in use can lead to significant energy savings (see also [11]). Sensors may be installed to verify whether a person is in the car. In the case of glass cars, sensors may also be used to check the lighting provided by external sources and to adjust lighting accordingly.  
**Recommendation:** switching off car lighting is a very cost-effective and simple method to increase energy efficiency.  
**Relevance:** all lift installations. |
| 23 | **Use automatic car fan control / switch-off fan** |
|     | Sometimes, a fan provides fresh air to the car. Independently of its efficiency, it is permanently using energy when running.  
**Recommendation:** using an automatic control system (e.g. time or temperature controlled) for operating the car fan, if available, can reduce energy consumption.  
**Relevance:** all lift installations. |
| 24 | **Switch off other lift components when not in use** |
|     | Stand-by consumption can be a main driver of energy consumption; various strategies to switch off components exist. For shorter periods of non-usage, only some of the components may be switched off (“sleep mode”). Putting the lift back into standby operation will require only a short period of time (some seconds). For longer periods, for example during the night, more components can be switched off, (“deep-sleep mode”).  
**Recommendation:** components not in use should be switched off while the lift is not operating, while ensuring the safe operation of the lift.  
**Relevance:** all installations. |
| 25 | **Switch off comfort equipment when not required** |
|     | As pointed out above, it should also be checked whether non-lift comfort equipment must necessarily run 24 hours a day or if it can be put into sleep mode as well.  
**Recommendation:** check switching off comfort equipment.  
**Relevance:** all installations. |
| 26 | **Switch temperature control of machine room according to requirements** |
|     | Due to energy losses, heat is accumulated in the machine room. To avoid components from overheating or freezing, machine rooms sometimes need to be climate controlled. The settings for the temperature control should be adjusted appropriately for the equipment. Too narrow limits lead to higher energy demand than necessary.  
**Recommendation:** use temperature control in the machine room only when the temperature levels move outside acceptable limits.  
**Relevance:** all installations. |
### Table 6.5.7. Escalators energy concerns

<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>27</strong></td>
<td>Operate oil heater and cooler only when required</td>
</tr>
</tbody>
</table>
| | In hydraulic systems, hydraulic fluids are best used in certain temperature intervals (due to reasons of viscosity and safety of operation). To assure an adequate oil temperature, heating and cooling devices are used to keep temperature at a steady level.  
**Recommendation:** oil heating and cooling should only be engaged when the oil temperature leaves the normal operating temperature.  
**Relevance:** relevant both for new and existing installations with oil heaters and coolers. |
| **28** | Switch off car roof light/ shaft illumination after service |
| | The shaft and sometimes also the car roof have lighting which is necessary for service and maintenance work. This lighting should be switched off if not needed.  
**Recommendation:** check if illumination is switched off after service or use an automatic switch-off function.  
**Relevance:** all installations. |
| **29** | Check correct type and adequacy of lubrication |
| | Adequate lubrication (if required) of the guiding rails should be part of the regular maintenance programme to avoid unnecessary losses due to friction.  
**Recommendation:** check adequate lubrication where required.  
**Relevance:** all installations where lubrication is required. |
| **30** | Optimise traffic handling and management |
| | Optimising traffic handling and management can be both relevant for single installations as well for groups of installations. For lift groups energy consumption can be reduced by putting one or more installations into a sleep or deep-sleep mode during periods with low traffic, for example, during night time or at weekends, thus reducing or completely avoiding standby losses.  
**Recommendation:** check possibilities to use or switch off lifts and to optimise traffic handling.  
**Relevance:** new and retrofit installations where more than one transportation system is available. |
| **31** | Check benefits of using condition monitoring |
| | Modern technological solutions such as condition monitoring provide the possibility to check the state of operation of a lift. Irregularities in the mode of operation can also indicate problems that affect the energy efficiency of the installation.  
**Recommendation:** check benefits to use condition monitoring and to include information on energy consumption.  
**Relevance:** new installations and retrofits. |

#### 6.5.7. Features specific to energy-efficient escalators

Escalators are primarily found in locations operated by owners who have dedicated experts for energy issues (for example, commercial shopping centres or public traffic infrastructure). The running time of escalators is usually much longer than that of most lifts. A number of aspects concerning both lifts and escalators have already been discussed in section 7.3.1. Table 7-9 and Table 7-10 presents additional aspects specific to escalators.
### Table 7-9. Energy efficiency: Escalator drive system

<table>
<thead>
<tr>
<th>Drive system</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>Use high efficiency &amp; properly sized motor</td>
</tr>
<tr>
<td>As with lifts, the drive motors in escalators plus the hand rail motor should be selected from the most energy-efficient motors. This is relevant for both the main motor for moving the stairs as well as the hand rail drive. In addition, a motor should be chosen that also provides a good efficiency ratio when running outside the nominal point of operation. <strong>Recommendation</strong>: motors should be chosen to have a high efficiency both in terms of full load efficiency, but also in terms of part-load efficiency. <strong>Relevance</strong>: relevant for new installations and (larger) retrofits.</td>
<td></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Check for adequate gearing</td>
</tr>
<tr>
<td>As in geared lifts, gears are used in escalators to transform a torque-speed ratio. <strong>Recommendation</strong>: gearing in escalators should be very efficient due to the high share of running time. Planetary, helical and hypoid helical gears can for example reach higher efficiencies than worm gears (see Chapter 3). <strong>Relevance</strong>: relevant for new installations but also for (larger) retrofits.</td>
<td></td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>Check benefits of using variable speed drives / low speed mode / stop mode</td>
</tr>
<tr>
<td>When using a variable speed drive, the speed of the escalator can be reduced until the next passenger arrives. However, an additional frequency converter is necessary to thus adjust speed. This additional energy consumption has to be compared to possible gains. As an alternative or complementary option, it is also possible to set the escalator in a stop mode. <strong>Recommendation</strong>: check the benefits of using variable speed drives and using a low-speed mode and / or a stop mode. <strong>Relevance</strong>: relevant for new installations but also for (larger) retrofits.</td>
<td></td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>Check benefits of using regenerative drives</td>
</tr>
<tr>
<td>Escalators transporting loads in a downward direction offer the possibility to generate energy. Induction motors have an inherent regenerative capability that can be improved by using regenerative drives (see Chapter 3). This recovered energy can be used in the building, for other escalators, or it can be fed back into the power grid. <strong>Recommendation</strong>: check the benefits of using a regenerative solution. <strong>Relevance</strong>: relevant for new installations and for (larger) retrofits.</td>
<td></td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>Use high-efficiency bearings</td>
</tr>
<tr>
<td>Bearings are a source of losses in escalators. <strong>Recommendation</strong>: use low friction bearings for the operation of the escalator. <strong>Relevance</strong>: all installations.</td>
<td></td>
</tr>
</tbody>
</table>
Table 7-10. Energy efficiency: Other aspects of escalators

<table>
<thead>
<tr>
<th></th>
<th>Other aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td><strong>Check benefits of adjusting operation mode to load and passengers</strong></td>
</tr>
<tr>
<td></td>
<td>During periods with small loads or no load at all, speed and torque can be</td>
</tr>
<tr>
<td></td>
<td>adjusted by various means, for example, by using a pole-switching motor,</td>
</tr>
<tr>
<td></td>
<td>variable speed drives, or by adjusting the voltage settings of the motor</td>
</tr>
<tr>
<td></td>
<td>(star-delta switching).</td>
</tr>
<tr>
<td></td>
<td><strong>Recommendation:</strong> check benefits of adjusting speed and torque to current</td>
</tr>
<tr>
<td></td>
<td>load situations.</td>
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<td></td>
<td><strong>Relevance:</strong> all installations.</td>
</tr>
<tr>
<td>7</td>
<td><strong>Use energy-efficient lighting</strong></td>
</tr>
<tr>
<td></td>
<td>Some escalators are equipped with additional light sources to illuminate the</td>
</tr>
<tr>
<td></td>
<td>steps.</td>
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<tr>
<td></td>
<td><strong>Recommendation:</strong> use energy-efficient lighting systems (LEDs for example).</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> all installations.</td>
</tr>
<tr>
<td>8</td>
<td><strong>Use sleep-mode on escalator equipment</strong></td>
</tr>
<tr>
<td></td>
<td>For escalators that are set into a stop mode (e.g. outside of regular</td>
</tr>
<tr>
<td></td>
<td>opening times), some components (e.g. frequency converter, lighting) could</td>
</tr>
<tr>
<td></td>
<td>be switched off to minimize energy demand.</td>
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<tr>
<td></td>
<td><strong>Recommendation:</strong> switch off components when lifts are outside their</td>
</tr>
<tr>
<td></td>
<td>normal operating times (e.g. during night time).</td>
</tr>
<tr>
<td></td>
<td><strong>Relevance:</strong> new installations and retrofits with suitable equipment.</td>
</tr>
</tbody>
</table>

### 6.6. References


   http://www.umsicht.fhg.de/publikationen/studien/EnEff_KH_Az_23472_Abschlussbericht_Download.pdf.


8 Conclusions and Recommendations

There are currently over 4.8 million lifts installed in the EU-27 and, each year, another 115 thousand units are placed into service. Lifts are responsible for the consumption of 18 TWh of electricity which corresponds to 0.7% of the total European electricity consumption.

In addition, there are approximately 75 thousand escalator and moving walks units installed in the EU-27 with about 3.500 new units installed each year.

The monitoring campaign carried out during the project covered 81 installations throughout Europe: 74 lifts and 7 escalators. The main goal of this monitoring campaign was to create a data basis to make valid estimations of the energy consumed by lifts and escalators. For this purpose a monitoring methodology was developed based on previous work carried out by international standardisation bodies and other relevant institutions.

The monitoring results highlighted the relative importance of standby consumption, which in some installations can be as high as 90% of the overall lift electricity consumption. The proportion of standby to overall consumption is greatly influenced by the usage pattern. This explains the fact that the estimated proportion of standby to overall electricity consumption of lifts in the residential sector is dominant (68%), whereas in the tertiary sector it represents 41%.

This usage patterns also helps to explain the following effects: Lifts in the residential sector, although being the majority of lifts installed (64% of units), are responsible for only 35% or 7 TWh of the electricity consumed. Lifts installed in the tertiary sector with a more intensive use, consume about 11 TWh of electricity annually, which corresponds to about 1.5 % of the electricity consumed in that sector.

A technological assessment was carried out aiming at the characterisation of the existing technologies, as well as the identification of emerging energy efficient solutions which can provide electricity savings both in standby and in running of lifts and escalators. The most important key technologies identified include the following:

- Premium efficiency induction motors or Super Premium efficiency permanent magnet synchronous motors;
- Efficient pumps in hydraulic elevators
- Efficient drives with regeneration capability in buildings with intensive lift use;
- Efficient transmission and roping;
- Traffic management directed not only at efficacy when transporting passengers, but also at energy efficiency
- Low standby power components such as door operators, lamps, ventilators and displays

The technology assessment performance indicators, combined with the results from a market survey determining the main characteristics of the installed stock and of the monitoring
campaign, were used to provide a credible baseline for the evaluation of potential energy savings.

Using the best available technologies would produce savings in the standby consumption of over 70%. In particular, energy efficient lighting options and the use of electronic components with low standby power (e.g. controllers and inverter) were found to play a major role in this reduction. Turning off non-essential equipment or putting it into a very low power “sleep” mode, whenever possible, would produce even larger electricity savings.

The potential overall (running plus standby) savings are estimated to be of 11 TWh, considering that the Best Available Technologies are used, or up to 13 TWh if technologies that are being developed but not yet widely used in the lift industry are applied. These savings translate into a reduction of carbon emissions of around 4,9 Mtons of CO₂eq and 5,8 Mtons of CO₂eq, respectively, considering the current electricity production mix in Europe.

Concerning escalators our analyses came to the following results: The ability to adjust automatically the speed of the escalator to the passenger demand is a solution that can produce energy savings. The results of the monitored installations showed that escalators operating in “reduced speed” mode consume approximately half of the electricity consumed in normal operation mode.

The estimated electricity consumption of escalators in Europe is relatively modest (900 GWh), and a potential reduction of around 250 GWh (30%) could be feasible if all the escalators installed would be equipped with automatic speed controls and with low power standby modes.

However, before these potentials can be realized some barriers in the market need to be overcome that are present in the market today. In a further step, the most significant barriers were identified, as well as possible strategies and measures to overcome those barriers. The main barriers identified are:

- lack of information and awareness of the actual electricity consumption of lift and escalator systems;
- lack of information and awareness of the energy efficient technologies in the market;
- low state of knowledge on the economic efficiency of the technological measures;
- split incentives between general contractors, owners of installations as well as those paying for the energy consumption of installations.

These main barriers may be addressed by a combination of the following strategies:

- Raising awareness through campaigns and the provision of information material for relevant stakeholder groups, such as the main dissemination materials (available online at www.e4project.eu) developed in this project:

  a) “Options to improve lift energy efficiency”
  b) “Energy Efficient Elevators and Escalators – Technology Assessment”
c) “Barriers to and strategies for promoting energy-efficient lift and escalator technologies”
d) “Guidelines for new lift installations and retrofitting”
e) “Public Buildings Procurement Guidelines for Lifts and Escalators”

National energy agencies can play a major role to improve awareness towards the selection and proper operation of energy-efficient lift and escalator systems.

- Implementation of a harmonized standard for measuring and predicting the electricity consumption for lifts and escalators, based on the previous international work and on the methodology developed in this project.

- Inclusion of lifts and escalators into a future revised version of the EPBD Directive, providing an incentive to use energy efficient technologies both in new buildings and in retrofits.

- Implementation of energy labels similar to those already in use in some European countries, providing easily accessible and understandable information, for buyers and specifiers of lifts and escalators systems to support decision making processes.

- Minimum energy performance indicators to be defined in close cooperation with lift and escalator manufacturers (e.g. maximum standby consumption for all systems, and maximum specific consumption for non-residential high traffic installations).