Fraunhofer ISI

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Intelligent Energy Europe

E4 – Energy-efficient elevators and escalators

Guidelines for new lift installations and retrofitting

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1 Introduction

Energy consumption is an important aspect in the discussion about sustainable development. Energy demand is one of the major driving forces in the release of carbon dioxide in the atmosphere. Electricity demand in the EU27 has been constantly rising over the last decade, reaching a total of 2,843 TWh in 2007, according to Eurostat statistics. Energy efficiency is a crucial option in contributing towards more sustainable development: according to the International Energy Agency, end-use energy efficiency is seen as a possible major contribution to limiting global warning to an average of +2°C (IEA 2009).

Like other electrically driven devices, lifts and escalators consume electrical energy. The energy consumption of lifts is estimated to be around 3-8% of the electrical consumption in a typical building (Sachs 2005, p. 2; Report with the results of the monitoring campaign, 2010, p. 4). More than 4.5 million lifts and about 75,000 escalators are installed and operated in Europe (de Almeida et al. 2009b). These lifts consume about 18 TWh in the EU27; escalators are responsible for about 1 TWh (de Almeida et al. 2009b). Replacing and using the best available technology for all existing lifts and escalators is estimated to result in savings of electrical energy of about 65% (Table 1).

		Running (TWh)	Stand-by (TWh)	Total (TWh)	Savings (%)
Current technology	Lifts	8,673	9,706	18,379	-
	Escalators	822	82	904	
	Both	9,495	9,788	19,283	
Best available technology	Lifts	5,637	551	6,188	66 %
	Escalators	413	236	649	28 %
	Both	6,050	787	6,837	65 %

Table 1: Estimated energy demand (electricity) of lifts and escalators in the EU27 (source: de Almeida et al. 2009b)

The aim of this document is to give an overview of technological and organizational features that increase energy efficiency in new lift and escalator installations and for retrofits. Indirect energy requirements to produce raw materials, manufacture components, erect installations, accomplish repairs, do maintenance and to dispose of the installations are not part of this assessment. The demand for vertical transportation is assumed as an exogenous factor. Therefore it is not the intention to discuss substitution options, e.g. using stairs. This document should provide a comprehensive knowledge basis for a broad audience. By providing a list of features in section 4, it should help various stakeholders[1] directly or indirectly concerned with lifts and escalators to

[1] For example construction companies, architects, building equipment system designers, planners, policy-makers, energy agencies and professional associations, but also manufacturers of elevators and escalators

reflect and decide on measures to increase energy efficiency for existing and new installations.

2 System overview

Lifts and escalators are passenger transportation systems that increase the ease of crossing vertical distances between different floors of a building. Lifts are designed to move passengers and goods between different floors of a building by moving a cabin ("car") up and down a shaft. Escalators are passenger transportation systems providing vertical mobility by moving sets of stairs in an upward or downward direction between two floors. Moving walkways are very similar to escalators from a technical point of view, but provide horizontal movement to comfortably cross horizontal distances. Depending on the building structure and the users, these systems are a prerequisite to make it practical and comfortable to live and work several floors above or below the ground.

Both types of transportation systems use electrical drive systems and thus use electrical energy for operation. In addition to the drive system, further equipment is needed for operating these systems, including control systems and equipment to ensure comfort and safety for the users.

2.1 Lifts

Typically, two different principles for moving lift cars are found in practice: the first principle is using ropes to pull the car (therefore these systems are also referred to as "traction systems"). The alternative is to push the car from below by using a hydraulic piston.[2]

Figure 1 shows a simplified/schematic overview of a typical conventional traction system. The car used for transporting passengers or goods is connected by a cable to a counter-weight. The cable, and thus the car, is moved by a traction wheel connected to a drive system. The drive system is often located in a separate "machine room". Nowadays, lifts are often installed as "machine room-less" models, placing the drive system directly in the shaft, thereby reducing space requirements for lifts.

When the drive system is regarded more closely, several components can be distinguished. In the illustrated system the motor is linked to a traction wheel through a gearbox. The purpose of the gear is to transform the torque speed ratio provided by the

[2] For a discussion of the advantages and disadvantage of the two solutions, see for example de Almeida et al. 2009b or Thews 2009.

motor to the required ratio to move the car. Modern systems are also offered as solutions not requiring a gear, thus as “gearless” systems. Today, motors are usually connected to a frequency converter. Compared with classical motor systems, frequency controlled motors have the advantage of flexibly adjusting the motor speed, thus permitting for example soft-start solutions in lifts.

The use of a counter-weight reduces the net mass to be moved. The counter-weight is heavier than the empty car and often has the mass of the car plus 40 to 50% of the nominal load of the car. Therefore traction lifts actually only use little electrical energy when moving an empty car upwards – the car is mainly pulled up by the counter-weight moving downwards. Regarding the opposite case of a full car with maximum load travelling in an upward direction, the motor has to deliver additional traction since the load in the car plus the mass of the car exceeds the mass of the counter-weight.

In the case of a hydraulic lift (Figure 2), a hydraulic piston (usually buried in the ground, but also offered as an in-shaft solution for low-rise applications) is attached to the bottom of the car. The piston drives up the car. It is fed with a hydraulic fluid that is pumped from a reservoir into the piston. The pump is driven by an electric motor. Nowadays, pumps are also used with variable speed drives to adjust pressure levels and pump operation to the required conditions. As the piston must be long enough to span the vertical travelling distance, the lifting height of hydraulic lifts is limited. Hydraulic lifts are usually not equipped with counter-weights. Thus, when moving up the car, energy is required to lift the mass of the lift car plus the load in the car. Thus the net mass to be lifted is higher than for a balanced system, i.e. a system including a counter-weight. Lowering the car of a hydraulic lift is essentially done by gravity that pulls the car down, with the hydraulic fluid being fed back into the reservoir thereby breaking / limiting the speed of downward movement.

Hydraulic lifts often require a machine room for the oil pump and oil reservoir which is usually located at ground level beside the shaft. However, models are available on the market where the pump and the reservoir are included in the shaft itself, (making the machine room obsolete).

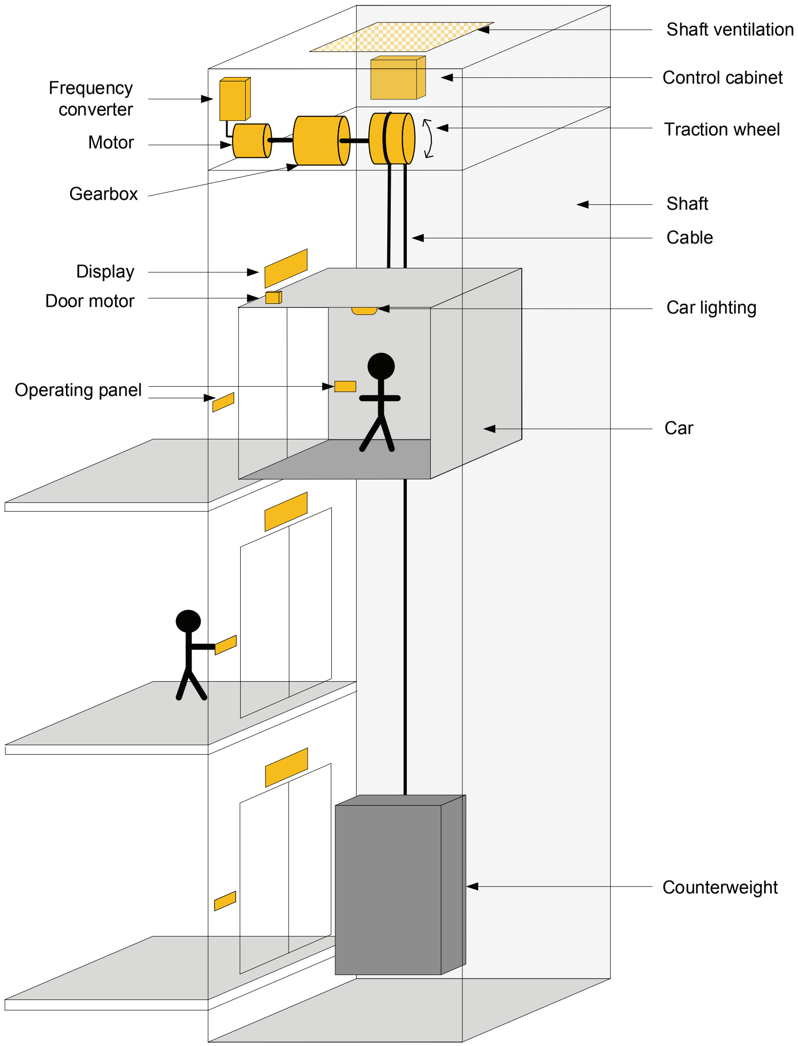

Figure 1: Simplified diagram of a typical conventional traction lift installation (Source: Fraunhofer ISI)

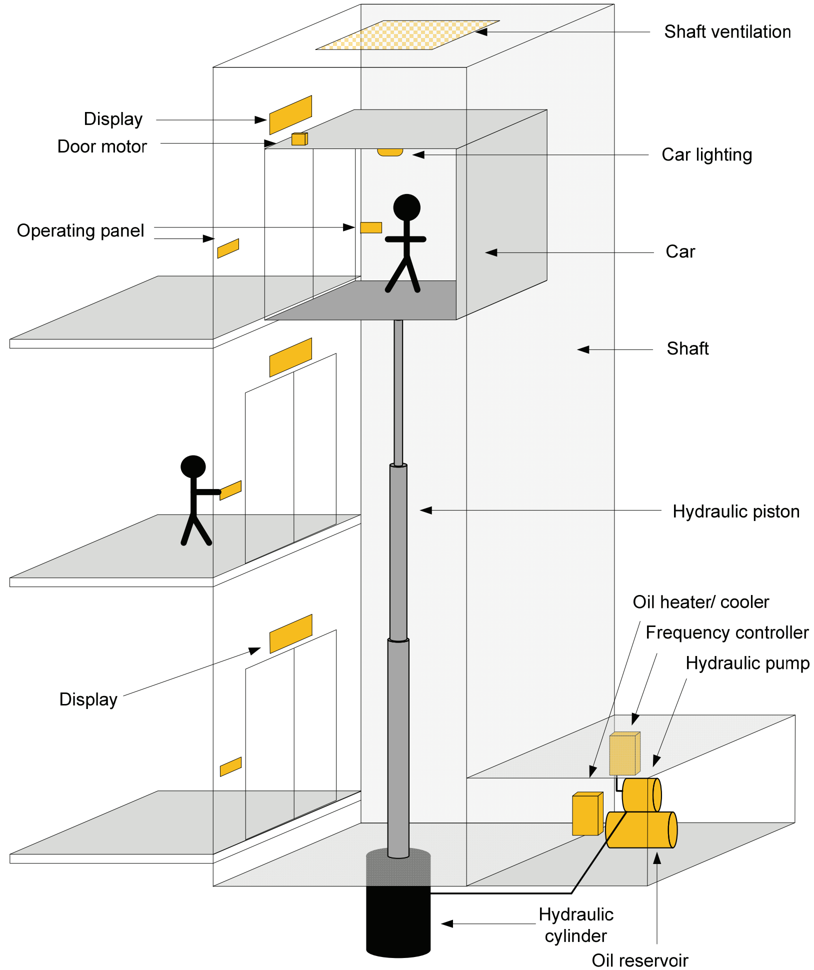

Figure 2: Simplified diagram of a typical conventional hydraulic lift installation (Source: Fraunhofer ISI)

Next to the drive system, additional system components are commonly part of both systems. They include:

- Car lighting

  Illumination of the car is provided by one or several light sources. Several types of illumination technologies are used, ranging from conventional light bulbs to modern LED illumination in recent installations. In addition to car lighting, further lighting is needed, mainly for maintenance purposes, e.g. on top of the lift car, in the lift shaft and the machine room. Depending on system configuration and usage, lighting can be a major contributor to overall consumption of electrical energy (e.g. Nipkow 2005, p. 34).
- Operating panels & displays

  Inside the lift car as well as on each floor, control panels are installed to call the lift to a floor or to select the desired destination. Further information is usually provided by these displays, e.g. indicating the current floor and/or movement of the lift.
- Control systems & safety devices

  Control systems are required to provide the desired functionality of the overall system by controlling, monitoring and coordinating all system elements. Safety devices are necessary to assure passenger safety during normal operation and in the case of malfunctions. Safety devices include for example emergency power supply, alarm systems, and intercoms.
- Doors

  While older lift systems or special purpose systems relied on manually operated doors, modern installations usually use automatically moving doors. They are moved by their own electrical motor system.
- Ventilation

  Lift cars are small spaces. To provide fresh air to a car, cars can be equipped with fans that provide an additional exchange of air between the lift car and the shaft.

The components listed above directly contribute to the consumption of electrical energy of an installation; their impact varies considerably from installation to installation, depending on their specific consumption and the frequency of usage.

Next to these „direct“ consumers that are connected to the power supply, a number of „indirect“ consumers in the systems can be found that also impact the overall energy consumption of the installation: e.g., guiding rails, gears and pulleys create friction and therefore influence the amount of electrical energy needed to move the car.

As a third aspect, the interface between the lift and the building has to be mentioned. Shaft ventilation can lead to thermal losses in the building. Lift shafts usually have vents which are necessary for ventilation. These vents act as a connection to the outside, i.e. letting in hot air in the summer and cold air in the winter, thus impacting on the heating or cooling requirements of the building. In addition, shaft walls are heat conductors and can lead to additional losses if not properly insulated (Clausnitzer et al. 2009, p. 39).

2.2 Escalators and moving walks

Escalators and moving walks essentially consist of a number of segments attached to a moving chain serving as steps for passengers (Figure 3). This chain is driven by an electric motor moving these steps. The steps are guided in tracks which keep them always horizontal while they move upwards or downwards or horizontally, so that people can comfortably stand on them during transit. Additionally, there is a handrail moving along with the steps for the user's safety; the handrail is driven by a separate motor which is regulated by a control system according to the speed of the steps. Once a step reaches the comb plate, it follows the step chain around a shaft and moves back to the other comb plate beneath the actual escalator, where it comes back to the surface.

Some installations can operate at various speeds, having a slow-speed mode in addition to the normal operating speed. When a passenger enters the escalator or moving walk, the steps are accelerated to normal operating speed. It is also possible to set an lift at stand-by mode, thus stopping the system completely.

When running empty, energy consumption is nearly constant for upward or downward movement, as one stair is always balanced by another stair moving in the opposite direction. When a load is transported by the escalator, i.e. when passengers are on the stairs, energy consumption is lower when running in a downward direction than in an upward direction.

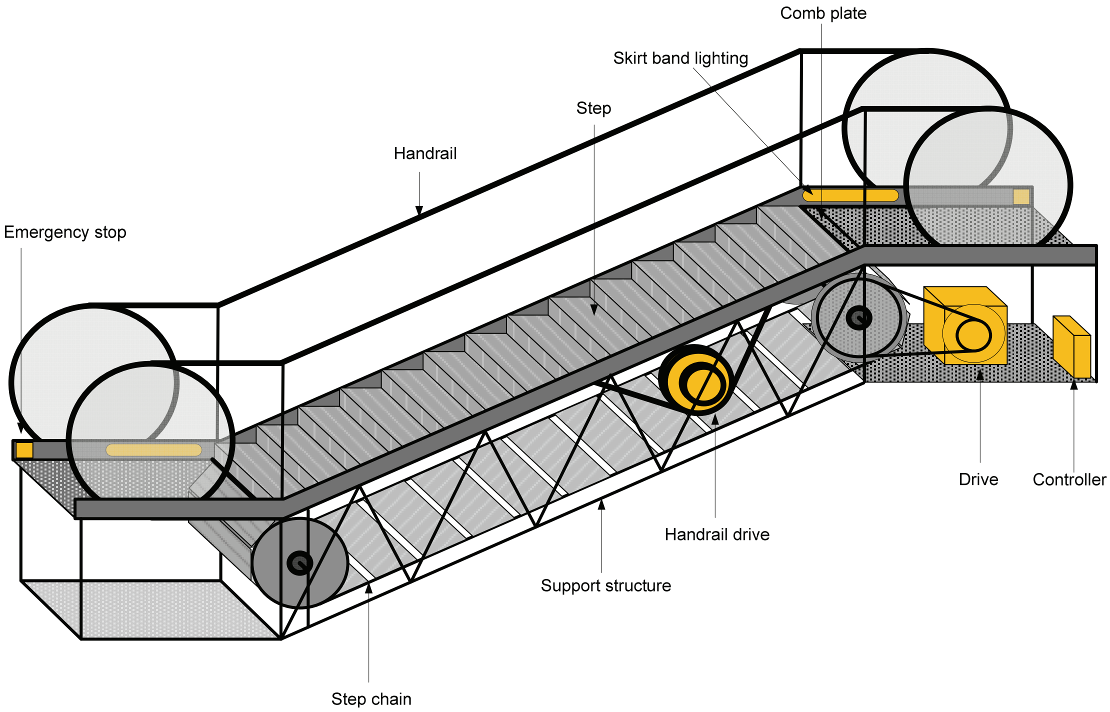

Figure 3: Simplified diagram of a typical escalator installation (Source: Fraunhofer ISI)

As in lifts, there are additional consumers in addition to the drive system, e.g. to provide safety. For this reason, some escalators are equipped with lighting to illuminate the steps.

2.3 Drivers for energy consumption

When analysing overall consumption of electrical energy of lifts, escalators and moving walks, three factors have to be taken into account:

- energy consumption during operation (the lift or escalator is running)
- energy consumption during stand-by (the installation is not operating, but waiting for the next passenger)
- the share of both operating modes (the share of time the installation is running or in stand-by, i.e. the frequency of usage).

The link between the three factors can be compared to a balance. The usage of the installation determines the location of the pivotal point. One side of the balance represents the stand-by consumption, the other one the running consumption. If the pivotal point were in the middle, and stand-by and running were equally important, there would be equal importance of both factors. In the example visualised in Figure 4, the lever for stand-by on the balance (right side) is much longer than the lever for operating or running consumption (left side). Yet running is much heavier than stand-by (i.e. overall running consumption is much higher), thus overall consumption is essentially determined by the running consumption. It is important to keep this link between the three factors in mind when trying to identify measures to optimise energy efficiency of an installation.

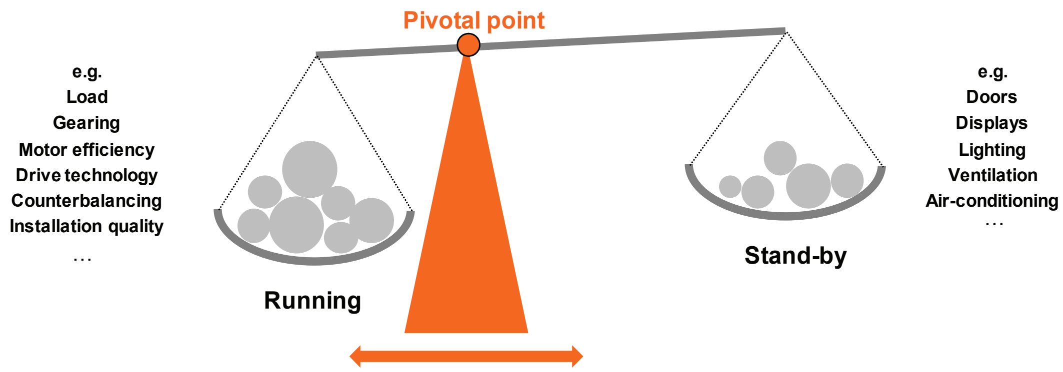

Figure 4: Link between determining factors for overall energy consumption (Source: Fraunhofer ISI)

The first two factors, energy consumption during operation and stand-by, are technological properties of the system components (e.g. consumption of a light source, losses of a pulley or efficiency of a motor). These values are in principle fixed once during planning and installation. However, these values may change during the life-time of the installation (e.g. due to increased friction as a consequence of ageing and usage).

The third factor, the relative shares of running and stand-by, mainly depend on exogenous factors that do not depend on the components, i.e. the frequency of usage (number of trips for lifts, regular running hours of the escalator or moving walk). The frequency of use is subject to various factors such as opening times of the building where the installations is located, the building type (e.g. school vs. shopping mall), individual user preferences (e.g. preference for using stairs or installation), typical user characteristics (e.g. families, aged people) or the comfort and ease of access to the installations.

3 New installations and retrofits

To reduce the energy demand of lifts and escalators, new installations as well as the stock of existing lifts have to be addressed. Lifts and escalators have very long life-cycles. Even if all new installations were equipped with the best available technology and were used only to replace existing installations, but not as additional units, it would take several decades for a complete stock turnover. Sachs (2005, S. 3) estimates that also major renovation cycles are in the order of between 20-30 years, with some core elements such as cars and shaft remaining in the building throughout its lifetime, amounting to some 50 or 100 years. Therefore, the maximum saving potential in the existing stock of lifts will be realized only gradually, if the cycles of renewal and replacements remain constant.

The following paragraphs characterize first the situation for new installations and next the retrofit situation. They are based on an exchange of opinion with experts and stakeholders concerned with lifts and escalators.

3.1 New installations

New installations offer the widest range of possibilities to increase energy efficiency. Usually, new installations are constructed along with new buildings. The requirements for lifts and escalators are usually taken into consideration during the planning process of the building. Thus the highest degree of liberty for taking measures to increase energy efficiency is given at this time.

New lift installations mounted into staircases or added externally to buildings without (sufficient) lift capacity, however, may be subject to restrictions such as available space. These restrictions at installation level may influence the range of possibly available features that increase energy efficiency.

There are various motives for installing lifts in new buildings, such as:

- to comply with legal requirements
- for accessibility reasons (elderly or handicapped people among the users, high-rise buildings, etc.)
- to offer comfort to the users of the building,
- to transport goods and
- various other motives (e.g. image and style of the building, etc.)

A large number of different actors directly or indirectly influence the energy efficiency of the final installation, among them architects, lift companies, lift consultants, general contractors and their subcontractors as well as market surveillance and notified bodies.

In the case of new installations, it is often a general contractor who allocates the budget available for the installation and thereby restricts the range of potential models. He thus influences the possibilities of using energy-efficient equipment. The general contractor usually does not benefit from choosing energy-efficient technology. Thus, it probably depends on whether the final operator is involved in the process or not and whether this final operator is explicitly asking for energy-efficient equipment or not (see Duetschke, Hirzel 2010).

Final operators can be distinguished in two groups: those running many and large installations and those only occasionally confronted by the subject of energy efficiency. The first group of operators are for example operators of commercial buildings or airports. They often have a dedicated specialist for energy matters who asks for specific energy-efficient equipment, based on long experience and specialized knowledge. The second group does not ask explicitly for energy-efficient equipment for several reasons (e.g. lack of knowledge, awareness, etc.).[3]

3.2 Retrofits

Retrofits can be quite heterogeneous in practice; retrofitting ranges from the replacement of single components in existing installations to replacing the whole installation, only leaving existing infrastructure such as guide rails or the lift shaft. In both cases new components have to fit and work with older parts and components to a certain degree.

The scope of a retrofit depends on various factors, e.g. the age and the current state of the existing installation as well as possible changes in current legislation. Other factors may also be important: a lift required for the normal operation of a building (for example, high-rise buildings) may be retrofitted in several steps to minimize down-time, for example. The question whether to modernize or to entirely replace an installation depends on the individual case, taking into account both technological and financial aspects.

In contrast to new installations, replacements must be incorporated into existing infrastructure that is not necessarily compatible with standard or the most energy-efficient equipment. In a retrofit, given infrastructure from older installations thus limits the number of possible measures to increase energy efficiency (e.g. no space available to install a counter-weight).

Motives for retrofits often include one or more of the following:

- complying with legal requirements and safety standards (e.g. levelling accuracy, cabin doors)
- increasing reliability (i.e. avoiding down-time)
- improving comfort and style (e.g. riding comfort, interior)
- removal of barriers to accessibility
- reduction in costs (e.g. service and repair costs, energy consumption)

[3] A more detailed discussion of these issues is given in Duetschke, Hirzel 2010.

- reduction of space requirements by eliminating the machine rooms (using machine-room less lift systems)
- modernization together with the building.

Annual energy costs, especially in smaller installations, are often lower than annual costs for maintenance. Therefore measures to increase energy efficiency tend rather to be implemented along with other measures or only if considerable energy savings are expected.

In contrast to new installations, the owner or operator usually has a long experience with the installation. The split-incentive problem during retrofits tends to be smaller than for new installations, as the operator or owner is directly involved in the process. However, it may persist in another form as, for example, the operator of a lift does not necessarily pay the energy costs but rather the inhabitants or users of the building.

4 Features for energy efficiency

Lifts and escalators are individually engineered systems instead of off-the-shelf products or standardized products. Elevators in particular are very heterogeneous systems: they can be standard systems, more individualized 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, first of all frequency of use. There are only few features that are advisable in general.

Therefore, a list is provided identifying features that are possibly helpful to reduce energy consumption. It is compiled from project findings (e.g. de Almeida et al. 2009a, de Almeida et al. 2009b, Report with the results of the monitoring campaign, 2010) from discussions with experts and stakeholders (cf. Duetschke, Hirzel 2010) and from relevant literature (e.g. Nipkow 2005, Guideline VDI 4707, Draft International Standard ISO/DIS 25745-1, Beier 2009, Clausnitzer et al. 2009, Barney 2007). 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.[4]

In the following, several lists with features that can possibly help to 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.

4.1 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 European Commission 2009, pp. 60–63). Awareness and knowledge are crucial prerequisites for the appropriate design, selection, operation and maintenance of energy-efficient equipment. Table 2 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.

Awareness & knowledge	
1	**Educate sales and design staff**
	The role of a sales person is a very important one when offering and selling technology. During an expert consultation (cf. Duetschke, Hirzel 2010) it was repeatedly stated that sales personnel are often not sufficiently aware of the consequences of certain technological choices or available technological possibilities. **Recommendation:** especially manufacturing companies (but not limited to them) should sensitize their sales and design staff to issues of energy efficiency.
2	**Educate installation and maintenance staff concerning energy efficiency**
	Next to assuring and verifying comfort and safety during maintenance, maintenance personnel should also be sensitized 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. The role of the staff performing the installation is also very important, especially for lifts. This issue is further discussed in Table 6. **Recommendation:** sensitize installation and maintenance staff.

[4] A more detailed analysis with a focus on energy efficient technologies from a technical point of view can be found in de Almeida et al. 2009b.

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. Duetschke, Hirzel 2010). Checking offers from other companies could be helpful by having a baseline for comparison. Engaging an independent expert lift consultant may help to 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.

Table 2: Energy efficiency: Awareness and knowledge

When looking at specific installations, a first step in determining the best solution in terms of energy efficiency is to check, analyze and discuss the actual requirements and expectations. Table 3 provides a list of aspects that contribute to choosing energy efficiency solutions in this specification phase.

Specification	
4	**Check necessity of lift or escalator installation**
	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. **Recommendation:** 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. **Relevance:** new installations and retrofits located in buildings where more than one vertical transportation systems are found.
5	**Check location and number of installations**
	Selecting the appropriate location for lifts or escalators can increase comfort and ease for the users and it can help to reduce the number of required installations. **Recommendation:** 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 analyzed, 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 escalator. **Relevance:** especially relevant for new installations.

Table 3: Energy efficiency: Specification

4.2 Specific features for energy-efficient lifts

The previous section deals with aspects that are both relevant 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 5**).

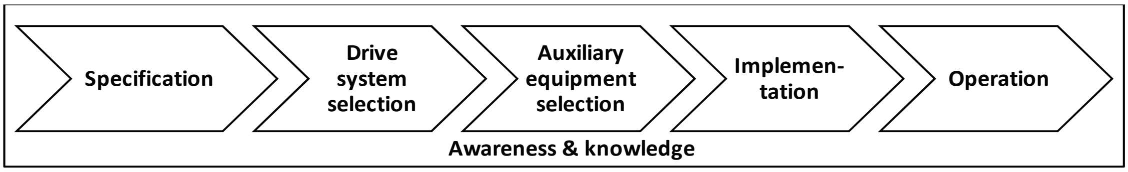

Figure 5: Aspects for energy-efficiency through the life-cycle of lifts (Source: Fraunhofer ISI)

Aspects for drive systems are discussed in Table 4, aspects concerning ancillary equipment are treated in Table 5.

	Design of the drive system
6	**Check dimensioning**
	The dimension of the car, the load and the speed determine among others the requirements for the drive system. **Recommendation:** 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 (2005, p. 37). **Relevance:** especially relevant for new installations, but also for (larger) retrofits.
7	**Check for appropriate drive technology**
	As described in section 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 (cp. Figure 4). Conventional hydraulic lifts have a higher running consumption than conventional traction lifts under comparable conditions (Sachs 2005, p. 2, Nipkow 2005, p. 7, Report with the results of the monitoring campaign, 2010). Nipkow (2005, p. 35) or ISO (Draft International Standard ISO/DIS 25745-1, p. 12) add that modern hydraulic concepts can provide similar efficiencies to modern traction lifts. **Recommendations:** it should be checked which technology is the best choice in terms of energy efficiency in a given case. **Relevance:** 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 stand-by consumption.

8	**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 means the configuration of how car and counterweight are connected to the motor, has a similar function as gearing, as it can help to 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 (2005, p. 38) proposes using planetary gears or gearless systems to increase energy efficiency. Discussing different solutions should help to increase energy efficiency. **Relevance:** especially relevant for new installations but also for (larger) retrofits.
9	**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 they are connected laterally. **Recommendation:** according to Clausnitzer et al. (2009, p. 44) and Nipkow (2005, 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.
10	**Check usage of high efficiency & properly sized motor**
	The efficiency of the motor driving an 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 (cf. for example de Almeida et al. 2009b). Over-dimensioning motors can however provide additional thermal operating safety according to (Nipkow 2005, p. 25). **Recommendation:** motors should be chosen to 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.

11	**Check benefits of using regenerative drives**
	Regenerative drives are systems that can convert or store breaking energy from a moving lift car. 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 to the electrical grid, depending (de Almeida et al. 2009b, pp. 17–23) on the configuration and local regulations. (Nipkow 2005, 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 (2200kg , 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. In conventional hydraulic systems, braking energy from a descending car is dissipated via a throttling valve. Recent hydraulic solutions allow for example to accumulate 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. **Recommendation:** especially for often running, large installations, using a drive system with regenerative capabilities is a possibility to reduce energy consumption. It is advised to check whether it is possible and permitted to use the recovered energy and it should be discussed whether the usage of the regeneration technology leads to higher stand-by consumption or not. **Relevance:** especially relevant for new installations but also for (larger) retrofits.
12	**Check usage of a frequency converter with automatic stand-by function**
	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. (de Almeida et al. 2009b, p. 20) The use of frequency converters can lead to additional stand-by consumption. Modern units provide an auto stand-by function, this means that internal components automatically switch to reduced or no consumption when not needed. **Recommendation:** using frequency converters without stand-by can help to decrease stand-by energy consumption **Relevance:** especially relevant for new installations but also for (larger) retrofits.

13	**Check usage and optimization of counter-balancing**
	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. Often a counter-balance has the same mass as a lift car plus half of the nominal load. Thus the lowest energy is required 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%[5]. Adjusting the mass of the counter-weight can thus be an option to reduce the average motor load and to reduce energy requirements. **Recommendation:** consider using a counter-weight to reduce the load the drive system has to lift and optimize it in accordance with the actual usage requirements. **Relevance:** especially relevant for new installations but also for (larger) retrofits.
14	**Reducing the mass of the car**
	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. **Recommendation:** check benefits of using a car with reduced mass. **Relevance:** especially relevant for new installations and (larger) retrofits that are often used and that do not have a counter-weight.

Table 4: Energy efficiency: Lift drive system

Design of ancillary lift equipment	
15	**Check necessity of additional non-lift comfort equipment**
	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 the energy consumption, especially when it runs permanently. **Recommendation:** check the necessity, consumption patterns/energy efficiency, and frequency of use of this additional equipment to contribute to reduce consumption. **Relevance:** new installations and retrofits.

5 Cf. the assumed load collective used in Nipkow 2005, Brzoza-Brzezina 2008.

16	**Use energy-efficient lighting & appropriate surface material**
	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 also de Almeida et al. 2009b, pp. 38-39). Avoiding dark surface materials and textures in the car interior can also contribute to reducing the energy consumption required by lighting. **Recommendation:** 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). **Relevance:** 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.
17	**Avoid stalled motor door operator**
	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 (Clausnitzer et al. 2009, p. 45). Thus these systems permanently require energy. **Recommendation:** door-locking mechanisms should be used that do not permanently require energy for the locking mechanism when the lift is not in use. **Relevance:** this is both relevant for new installations and (smaller) retrofits.
18	**Use energy efficient transformer and power supply**
	Some lift circuits require low voltage energy that is supplied by a transformer or power supply. **Recommendation:** the efficiency of this transformer or power supply during operation should be selected as high as possible, while stand-by consumption should be low (cp. Nipkow 2005, p. 34). **Relevance:** this is both relevant for new installations and (smaller) retrofits.
19	**Use energy-efficient components for all other components and equipment**
	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. **Recommendation:** 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. **Relevance:** this is both relevant for new installations and retrofits.

Table 5: Energy efficiency: Lift auxiliary equipment

When energy-efficient equipment is selected, the equipment has to be properly installed to make use of its full energy-saving potential. Table 6 discusses the role of installation quality and the lift-building interface.

Installation	
20	**Ensure installation quality**
	A factor influencing the energy consumption of an lift is the quality of the installation. Bad installation quality often negatively impacts 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 (Clausnitzer et al. 2009, p. 39). **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.

Table 6: Energy efficiency: Lift installation

Next to their energy efficiency, the running time and usage of these components is a very important factor for overall energy demand. A list of different operational and organizational measures to reduce energy consumption can be found in Table 7.

Operation	
22	**Switching off car lighting when not in use**
	Some light sources such as modern LEDs can be dimmed and switched without reducing their life time (de Almeida et al. 2009b, p. 38). Provided that such light sources are installed in an lift, switching off the car lights when an lift is not in use can lead to significant energy savings (see also Nipkow 2005:34). 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 of to increasing 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 stand-by 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 whether 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.

27	**Operate oil heater and cooler only when required**
	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	**Optimize traffic handling and management**
	Optimizing 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 stand-by losses. **Recommendation:** check possibilities to use or switch off lifts and to optimize 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 an lift. Irregularities in the mode of operation can be an indicator to identifying problems also affecting 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.

Table 7: Energy efficiency: Lift operation

4.3 Specific features for energy-efficient escalators

Escalators are primarily found in locations (for example, commercial shopping centres or public traffic infrastructure) operated by owners who have dedicated experts for energy issues. 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 4.1. Table 8 and Table 9 present additional aspects that are specific to escalators.

	Drive system
6	**Use high efficiency & properly sized motor**
	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. **Recommendation:** motors should be chosen to have a high efficiency both in terms of full load efficiency, but also in terms of part-load efficiency. **Relevance:** relevant for new installations and (larger) retrofits.
7	**Check for adequate gearing**
	As in geared lifts, gears are used in escalators to transform a torque-speed ratio. **Recommendation:** 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 (de Almeida et al. 2009b, p. 45). **Relevance:** relevant for new installations but also for (larger) retrofits.
8	**Check benefits of using variable speed drives / low speed mode / stop mode**
	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. **Recommendation:** check the benefits of using variable speed drives and using a low-speed mode and / or a stop mode. **Relevance:** relevant for new installations but also for (larger) retrofits.
9	**Check benefits of using regenerative drives**
	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 (de Almeida et al. 2009b, p. 46). This recovered energy can be used in the building, for other escalators or it can be fed back into the power grid. **Recommendation:** check the benefits of using a regenerative solution. **Relevance:** relevant for new installations and for (larger) retrofits.

10	**Use high-efficiency bearings**
	Bearings are a source of losses in escalators. **Recommendation:** use low friction bearings for the operation of the escalator. **Relevance:** all installations.

Table 8: Energy efficiency: Escalator drive system

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

Table 9: Energy efficiency: Other aspects for escalators

5 Summary & Conclusions

The relevance of applying best available technology for lifts and escalators was pointed out in the first section. By using the best available technology, savings of 65% in the overall lift stock are possible (de Almeida et al. 2009a).

Energy in lifts and escalators is consumed in various system components. A general overview of relevant system components was given in section two and the link between running consumption, stand-by and the usage frequency was described.

Maximizing overall energy savings of lift and escalators in practice means addressing both new installations as well as retrofits. In section 3, the differences of the two situa-tions and the implications for energy efficiency were discussed.

This discussion is followed by an overview of features and aspects that could possibly increase the energy efficiency of lifts and escalators. Each feature is explained and a recommendation is given in the prior section. This overview does not claim to be either exclusive or exhaustive, but is intended as a general list of possibly interesting features as a first guideline. When optimum systems are to be designed, expert knowledge is a prerequisite, as many features are often not independent of each other. It is often advisable to consult experts to clarify the individual situation.

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