

Energy efficient elevators and escalators

Carlos Patrão
Dep. Electrical Engineering
Coimbra, Portugal
carlospatrao@isr.uc.pt

João Fong
Dep. Electrical Engineering
Coimbra, Portugal
joaofong@isr.uc.pt

Luc Rivet
Belgium
L.Rivet@ela-aisbl.org

Aníbal de Almeida
Dep. Electrical Engineering
Coimbra
Portugal
adealmeida@isr.uc.pt

Keywords

elevators, lifts, escalators, energy efficiency, stand-by consumption, barriers and policies for energy efficiency, elevator drives

Abstract

Elevators and escalators are the crucial element that makes it practical to live and work several floors above ground – more than 4,3 million units are installed in Europe. Due to ageing of the European population the installation of elevators in single family houses is experiencing a significant growth, as well as equipping existing buildings. Elevators use about 4% of the electricity in tertiary sector buildings. High untapped saving potentials exist with respect to energy-efficient technologies, investment decisions and behavioural approaches, in these sectors. This paper presents preliminary results from the IEE project E4, whose overall objective is the improvement of the energy performance of elevators and escalators, in tertiary sector buildings and in multi family residential buildings.

The project is characterizing people conveyors electricity consumption in the tertiary sector and in residential buildings in the EU. The installed park is characterised by a survey among elevators national associations in each country. An assessment of the barriers has been made in the first phase of the project and will be presented.

Monitoring campaigns in elevators and escalators are being conducted in each country according to a common developed methodology. More than fifty elevators and escalators will be audited. This will allow the collection of load curves (start up, travel up and down, travel full and empty), including the characterization of standby consumption. Standby consumption of

an elevator can represent up to 80% of the total energy consumed per year, and can be drastically reduced.

This paper presents the preliminary results of the first ten audits performed in Portugal by ISR-UC.

Introduction

In the EU-25 there are more than 4,3 million elevators and 85 thousand escalators and moving walks. Every year 125 thousand new elevators and 5 thousand new escalators and moving walks are installed [according to extrapolation of ELA-Elevator market statistics 2005]. Therefore, it is very important to characterize people conveyors (elevators and escalators) in terms of electricity consumption and technologies in the tertiary sector and in residential buildings in the European Union. It is necessary to promote the efficient use of electricity in this type of loads through the application of cost-effective energy efficient technologies available or emerging in the market. Energy efficient technologies can save a large percentage of the used electricity in a cost-effective way. The type of loads addressed in this paper is growing fast due to the expansion of the built area and because of the need to ensure adequate mobility to the elderly and handicapped population.

Generally, hydraulic elevators used in relatively low-rise buildings are much less energy efficient than the electric traction elevators used in higher rise buildings, though new types are being developed that match up to the energy efficiency of traction lifts. Earlier generation hydraulic elevators can use 3 times more electrical energy than traction elevators. Until the year 1995 at least two thirds of all elevator installations were hydraulic, then this trend began to change and in 2004 more

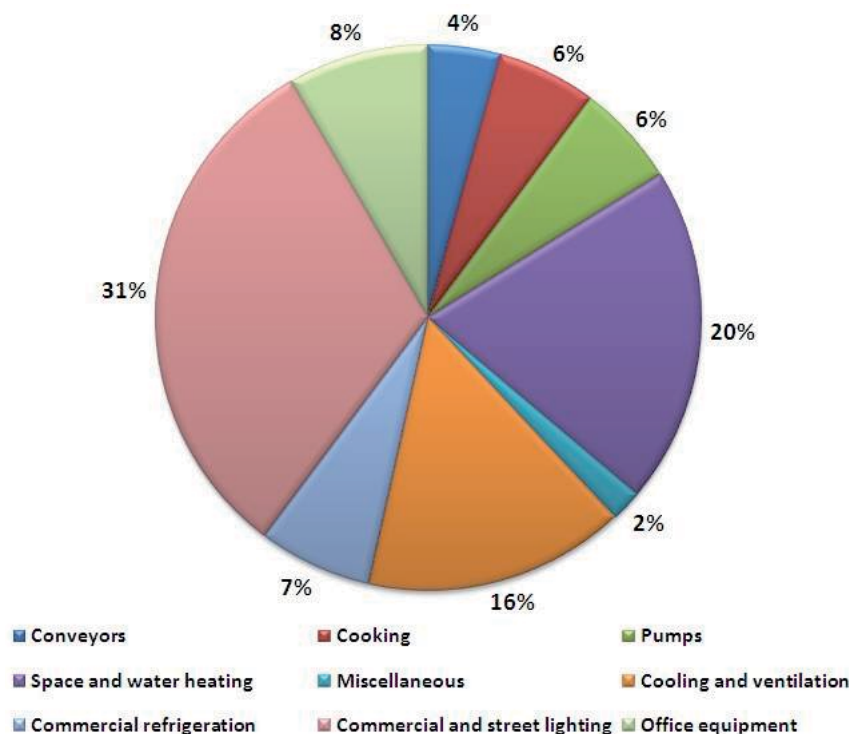


Figure 1. Electricity consumption breakdown in tertiary sector buildings in the EU [Source EC-JRC]

than 80% of all elevators sold were using traction technology [Gemici, 2005].

Usually traction elevators have counterweights, which are connected to the cabin by a pulley, and therefore it descends when the elevator is rising, and vice versa. New technologies and best practices namely motors and drives, regeneration converters, better control software, optimisation of counterweights, direct drives versus rope traction elevators, cabin lighting, etc. can yield significant savings. Within a drive class the best performing elevators can use up to 80% less electricity than the least efficient ones.

Electricity consumption in the tertiary sector in EU-25 by 2020 is foreseen to be 950TWh. Elevators and escalators now represent 4% of the total electricity consumption in the tertiary sector, with a trend for a significant increase of this share. Since potential savings of over 50% are possible, the impact of this project is the reduction of 20-25 TWh, translating into the reduction of 9-11 Mtons of CO₂ emissions. Additional savings are possible in the residential sector, particularly in multi-family buildings. Energy-efficient elevator and escalator technologies can also lead to decreased maintenance requirements, less downtime and increased safety.

The E4 project

The E4 project [E4-Energy Efficient Elevators and Escalators, www.e4project.eu] is targeted at the improvement of the energy performance of elevators and escalators, in the tertiary sector (hotels, hospitals, schools, shopping centres, office buildings, etc.) and in multi family residential buildings.

The countries directly involved in the project are Germany, Italy, Portugal and Poland, covering different regions of the EU. The European Lift Association (ELA) with agencies in most

EU countries also participates in the project, providing market characterisation and together with other partners allowing a large replication potential in other countries.

The aim of this project is to characterize people conveyors (elevators and escalators) electricity consumption in the tertiary sector and in residential buildings in the European Union, and promote the efficient use of electricity in this type of loads through the application of the best available technologies in the market.

The main objectives of E4 project are:

- to contribute to the market transformation of the service sector buildings and residential buildings, by improving the awareness of best practice solutions to provide vertical mobility;
- to provide recommendations and guidelines to promote those practices;
- to promote the improvement of energy performance of elevators and escalators in the tertiary sector (hotels, hospitals, schools, shopping centres, office buildings, etc.) and in multifamily residential buildings.

In total, between the partners of the project, monitoring of 50 elevators and or escalators will be performed. The monitoring campaign will be carried out in a number of selected buildings of the residential and tertiary sectors. This paper presents the preliminary results of the first ten audits preformed in Portugal by ISR-UC:

- 2 hydraulic elevators;
- 8 traction elevators;
- 2 escalators.

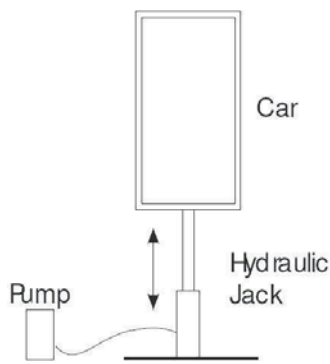


Figure 2. Basic components of hydraulic elevators

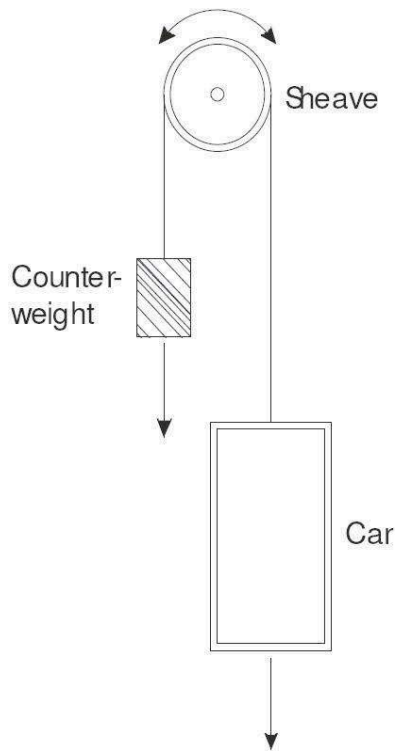


Figure 3. Basic components of traction elevators

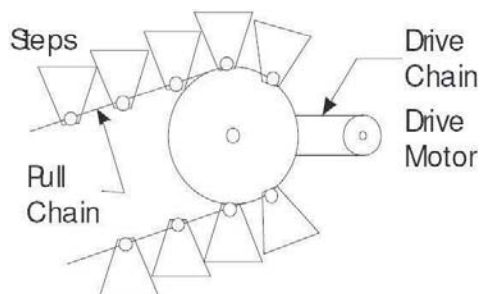


Figure 4. Basic components of an escalator

Elevators and Escalators

Elevators and escalator are systems used to provide vertical mobility in good comfort conditions. Impressive technology developments have been carried out in recent years in motors, electronic speed controls, mechanical transmissions, etc., which can dramatically reduce the electricity consumption of this systems.

HYDRAULIC ELEVATORS

The basic components of hydraulic elevators are shown in the figure 2.

This type of elevator uses a hydraulic cylinder to move the car. An electric motor drives a pump which forces a fluid into the cylinder moving the car up. When descending, an electric valve opens and the fluid is allowed to drain (slowly) from the cylinder into the tank.

Since they typically do not have a counterweight, the entire potential energy is wasted as heat, making hydraulic elevators less efficient solutions, sometimes consuming three times more electricity than traction elevators [Sachs, 2005]. The most recent hydraulic systems have now incorporated variable voltage variable frequency drives (VVVF) and an accumulator that acts as a hydraulic counterweight. Their energy performance has dramatically been improved with these new developments.

Hydraulic elevators are available for lifts up to a rated speed of 1m/s. The maximum travel distance for this type of elevators is around 18 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 and this way it is less attractive to use hydraulic elevators when you have a better alternative [CIBSE, 2008].

TRACTION ELEVATORS

While hydraulic systems rely on pushing the elevator car up and down, roped elevators pull the elevator cab using ropes or cables. In traction elevators the car is suspended by ropes rapped around a sheave that is driven by an electric motor. The weight of the cab is usually balanced by a counterweight that equals the mass of the cab plus 45% to 50% of the rated load. The purpose of the counter weight is to maintain a near constant potential energy level in the system as a whole, heavily reducing energy consumption.

There are two main types of traction elevators: geared and gearless (direct drive). Geared elevators use a reduction gear between the motor and the sheave to reduce the speed of the cab, while gearless elevators the sheave is directly coupled to the motor. New technologies and best practices, namely energy efficient motors and drives, better control software, optimisation of counterweights, direct drives instead of inefficient gearboxes, cabin lighting, etc. can yield significant savings. The most efficient systems have a Variable Speed Drive (VSD) that can provide significant energy savings, by allowing regenerative braking. Within a drive class the best performer's elevators can use up to 80% less electricity than the least efficient.

ESCALATORS

Escalators, like moving walks, use an electric motor that drives through a powertrain a system of moving steps.

Table 1. Summary of main applications [GIBSE, 2008]

Type of elevator	Typical applications	Advantages	Disadvantages
Hydraulic	Low rise 2-6 floors	Low cost	Slow, high energy use, maintenance issues
Traction Machine room-less	Low-Mid rise 2-10 floors	Easy installation, energy savings, faster then hydraulic option	Higher cost than hydraulic option
Traction Geared	Mid rise 3-25 floors	Low cost for application	Speed, energy consumption
Traction Gearless (direct drive)	High rise over 25 floors	High speed	High cost

Table 2. Elevator market statistics [Source: ELA-Elevator market statistics 2005]

Country	Existing elevators in operation (2005)	Estimated market (2005)
Austria	72.148	2.855
Belgium	77.000	2.722
CH (*)	164.220	6.791
Germany	631.000	11.450
France	475.000	11.604
Denmark	26.800	855
Finland(*)	50.000	840
Italy	790.000	17.900
Luxemburg	7.500	500
Norway	28.500	1.051
Netherlands	77.800	3.373
Portugal (*)	106.700	4.737
Spain	680.873	27.322
Sweden (*)	108.300	1.328
Greece (*)	308.000	8.475
Polland	70.000	2.000
Czech Republic	77.500	1.314
Hungary	32.950	1.000
UK	240.000	9.499
Total	4.189.191	115.616

(*) some of the values are estimated.

Escalators are moving steps design to transport people, over a short distance, between two landings. They are driven by an electric motor that powers the steps and handrail which move 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 low rise building applications, such as one storey rises in commercial buildings, and in high rise installations, such as in deep underground metro stations.

SUMMARY

The Table 1 presents a summary of the main applications, advantages and disadvantages of each type of elevator.

ELEVATORS MARKET ANALYSIS

Until 1998, hydraulic elevators were the most commonly installed solution, due to their low cost, security, low maintenance costs, and very easy installation. At that time, hydraulic

elevators sales in Europe represented about 60% of total market share. In 1995, with the appearance of the machine room-less traction elevator this tendency begun to decrease [Çelik and Korbahti, 2006].

Table 2 presents an estimation of the total installed elevators and estimated market in 2005.

Europe is estimated to have more then 4.3 million elevators installed, with Italy being the country with the highest number of installed elevators followed by Spain and Germany. The figure 5 shows the market share, in percentage, for each country.

Barriers

One of the aims of the E4 project is to help overcome some important obstacles for investments and behavioural changes which are mainly caused by socio-economic framework conditions in the target sectors, but also market failures, transaction costs, or imperfect information as well as market barriers on the supply side:

- Lack of awareness of building owners, investors and managers in private companies as well as public authorities, due to

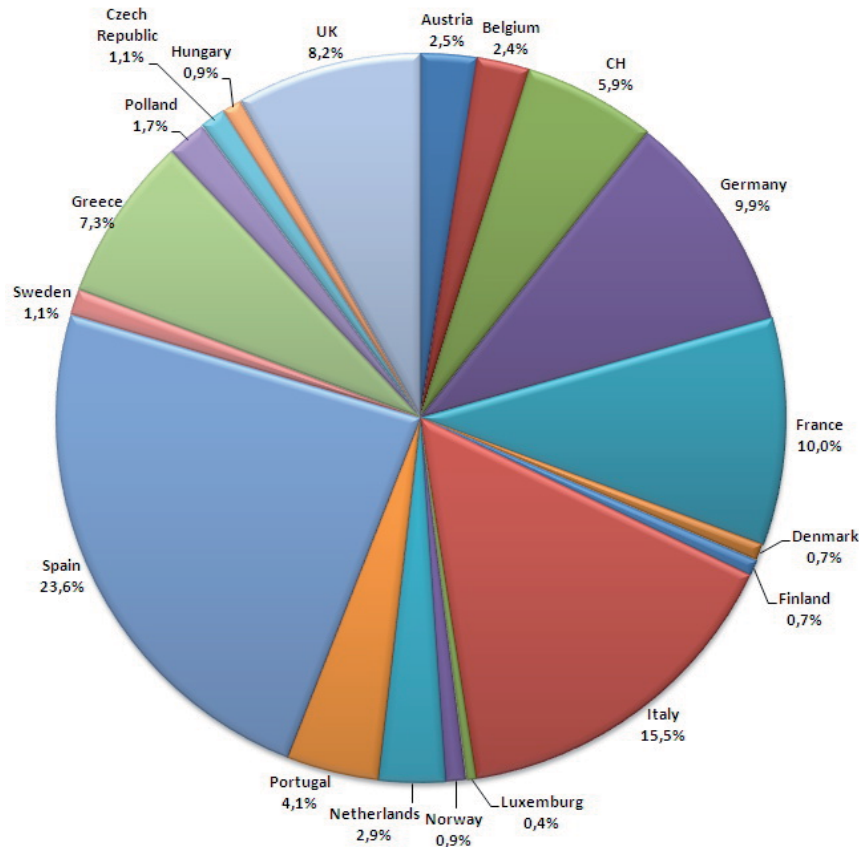


Figure 5. Estimated market share by country [Gemici, 2006]

the fact that the energy cost share is usually low, and investments in energy efficiency do not affect the core business;

- Large transaction costs, which generally include costs of gathering, assessing and applying information on energy savings potentials and measures, as well as costs to negotiate with potential suppliers, consultants or installers;
- Lack of information about energy consumption patterns and therefore the profitability of energy saving measures cannot be properly assessed, costs for metering and data management, and investment costs for the metering devices may prevent organizations from installing the appropriate equipment;
- Internal decision making and investment priority setting depending on criteria such as pay-back time, but also on soft factors such as the status of energy efficiency, image, attitudes of those responsible for energy management within the organization, or shared responsibilities between different departments (operation/investments);
- Split-incentives in building energy conservation, i.e. owners of buildings who do not pay the energy costs, are typically interested in low first cost solutions.
- Lack of sufficient market structures and access to energy service companies, energy consultancies, energy agencies, etc.
- High cost of advanced emerging technologies due to lack of economies of scale in their production.

The project will address these barriers and will try to contribute to their removal through improved information and raised awareness as well as stimulate adequate supporting policies.

Policies and Regulation

Environmental concerns have triggered, in the last decades, a number of energy conservation policy measures that aim at improving the world's sustainability.

In 2005, the European Commission issued the Directive 2005/32/EC on the eco-design of Energy-using Products (EuP), such as electrical and electronic devices or heating equipment. The directive defines conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics improving the overall environmental impact of such products. However, elevators and escalators are systems individually engineered for each application, rather than commodity products, and therefore are not covered by this Directive.

The building sector is responsible for 40% of Europe's energy demand and presents a large potential for savings which is estimated at 28%, and which in turn can reduce the total EU final energy use by around 11%.

With the purpose of realizing this potential the Energy Performance of Buildings Directive (EPBD) was adopted. The directive sets minimum requirements on the energy performance of new buildings and of buildings subject to major renovation and also a certification and classification scheme aimed at raising the awareness of energy use in buildings. It presents a great challenge

for the transformation of European building sector towards energy efficiency and the use of renewable energy resources.

Unfortunately, the directive does not cover people's conveyors which represent an estimated 4% of the energy consumption of buildings in the tertiary sector.

In Germany, the Association of German Engineers (VDI) is working on a guideline, VDI-Guideline 4707, "Lifts – Energy Efficiency", which will be released in early 2009. The guideline aims at the specification and representation of the energy demand and consumption of lift systems using harmonized criteria based on the determination of energy demand and consumption. A measuring methodology is defined and so are the measuring devices to be used. An energy-efficiency certificate including a classification is emitted by the manufacturer, following the rules set in the guidelines. The energy class of the elevator is to be publicly affixed in the elevator, as a label, similar to other electrical products.

The regulation is expected to further improve the penetration of energy efficient technologies in German speaking countries. Similar regulation is currently being discussed on European and International standardization organizations.

Methodology used

It is very important that all the partners of the E4 project follow the same methodology when performing their measurements in elevators or escalators. For this purpose a methodology for the monitoring campaigns was developed, based on the following documents:

- Draft International Standard ISO/DIS 25745-1 Energy Performance of Lifts and Escalators – Part 1: Energy Measurement and conformance, 2008;
- EN 60359:2002 Electrical and electronic measurement equipment - Expression of the performance;
- Nipkow J. Elektrizitaetsverbrauch und Einspar-Potenziale bei Aufzuegen, Schlussbericht November 2005, Im Auftrag des Bundesamtes fuer Energie;
- Lindegger Urs, Energy estimation: Document for E4, ELA, VDI & ISO, 11 June 2008;
- Gharibaan Esfandiar, Load Factor for Escalators, EG (09/05/2008).

A detailed description of the methodology can be found in project's website (www.e4project.eu).

Energy consumption

The energy consumption of an elevator or escalator is very dependent on the number of travel cycles performed during one year. The calculations expressed on this paper were made according to the methodology developed in the scope of the E4 project. Because of the difficulty in the acquisition of this type of data, the number of travel cycles was considered to be the same in buildings of the same sector.

TRACTION ELEVATORS TYPICAL CYCLE

The figure 6 shows a typical cycle of a traction elevator. In this case, this elevator cycle was taken from "Elevator D".

The initial transient, typical of a direct starting of an AC motor, is evident. In this case the starting active power reaches more than three times the nominal active power of the motor. During the "travelling down" it is necessary to overcome the difference of weight between the elevator car (in this case empty) and the counterweight. When "travelling up", since the counterweight is heavier than the elevator car, the active power necessary 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. In elevators with regenerative technologies the energy used to brake the elevator, and otherwise dissipated in the form of heat, is used to produce electrical energy.

HYDRAULIC ELEVATORS TYPICAL CYCLE

The elevator cycle of a hydraulic elevator is illustrated in the figure 7.

When "travelling down", the total active power required by the hydraulic elevator 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 elevator, corresponds to the opening of the valve to let the hydraulic fluid flow back to the tank.

Travel cycle energy consumption

The travel cycle consumption of an elevator is greatly dependent on the number of floors, the technology used, weight in the car, etc. In the next graphic the energy consumption for one travel cycle of each audited elevator is presented.

It is clear that the two hydraulic elevators have the highest cycle consumption of all analysed elevators, even if this consumption is compared with traction elevators of higher rise height.

Standby energy consumption

The figure 9 presents the standby consumption and the running mode consumption, in proportion to the overall consumption of the elevators audited.

From this previous graphic it is clear that standby consumption in elevators is a very important issue. Standby consumption represents from 24.6% to 79.6% of the overall consumption of the elevator. This standby consumption is due to the control systems, lighting, floor displays and operating consoles in each floor and inside the elevator cabin. In the analyzed elevators the standby annual consumption goes from 243 kWh to 2800 kWh.

The main reason for the proportion of standby to running mode energy consumption in "elevator D", is that the lighting inside the elevator cabin switches off 40 seconds after the weight sensor "feels" that there is no one inside.

Although "Elevator F" has one of the most efficient technologies for elevators in the market (MRL – permanent magnet motor), it has the highest standby consumption percentage in relation to overall consumption. This elevator consumes 2271 kWh/year in standby mode and around 582 kWh/year in running mode.

Hydraulic elevators running mode consumption largely overcomes the standby energy consumption, although it is not negligible since it represents from 2000 kWh/year to 2800 kWh/year, in the analysed hydraulic elevators.

Table 3. Main characteristics of the elevators audited

Elevator	Description	Control	Type of building	Year of installation	Velocity (m/s)	Nominal load (kg)	Motor nominal power (kW)	Nº of stores
A	gearless traction elevator	Electro-mechanic	Residential	1982	0,6	300	3,3	3
B	traction elevator with VSD	Electronic	Residential	2000	1	430	5,5	9
C	gearless traction elevator	Electro-mechanic	Residential	1988	1	450	6,4	13
D	geared traction elevator	Electronic	University	1997	1	630	11	9
E	geared traction elevator with permanent magnet motor (MRL)	Electronic	Office	2005	1	385	5,5	3
F	geared traction elevator with permanent magnet motor (MRL)	Electronic	Shopping center	2006	1	1600	16	4
G	hydraulic elevator	Electronic	Office	2005	0,63	640	14,7	5
H	hydraulic elevator	Electronic	Health clinic	2007	0,63	950	16	6

Table 4. Main characteristics of the escalators analysed in this paper.

Escalator	Description	Control	Type of building	Year of installation	Velocity (m/s)	Motor nominal power (kW)	Height
A	escalator with VSD	Electronic	Shopping center	2006	0,5	9	10 m
B	escalator with VSD	Electronic	Supermarket	2006	0,5	5,8	18 m

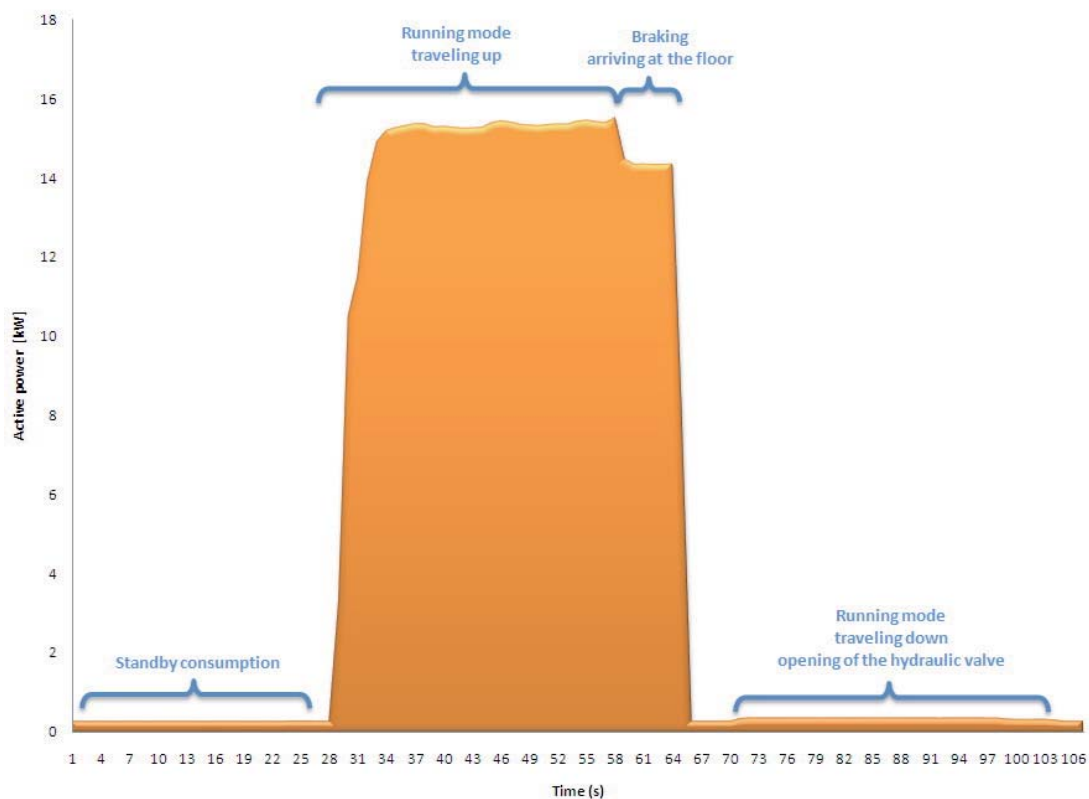


Figure 6. Typical cycle of a traction elevator

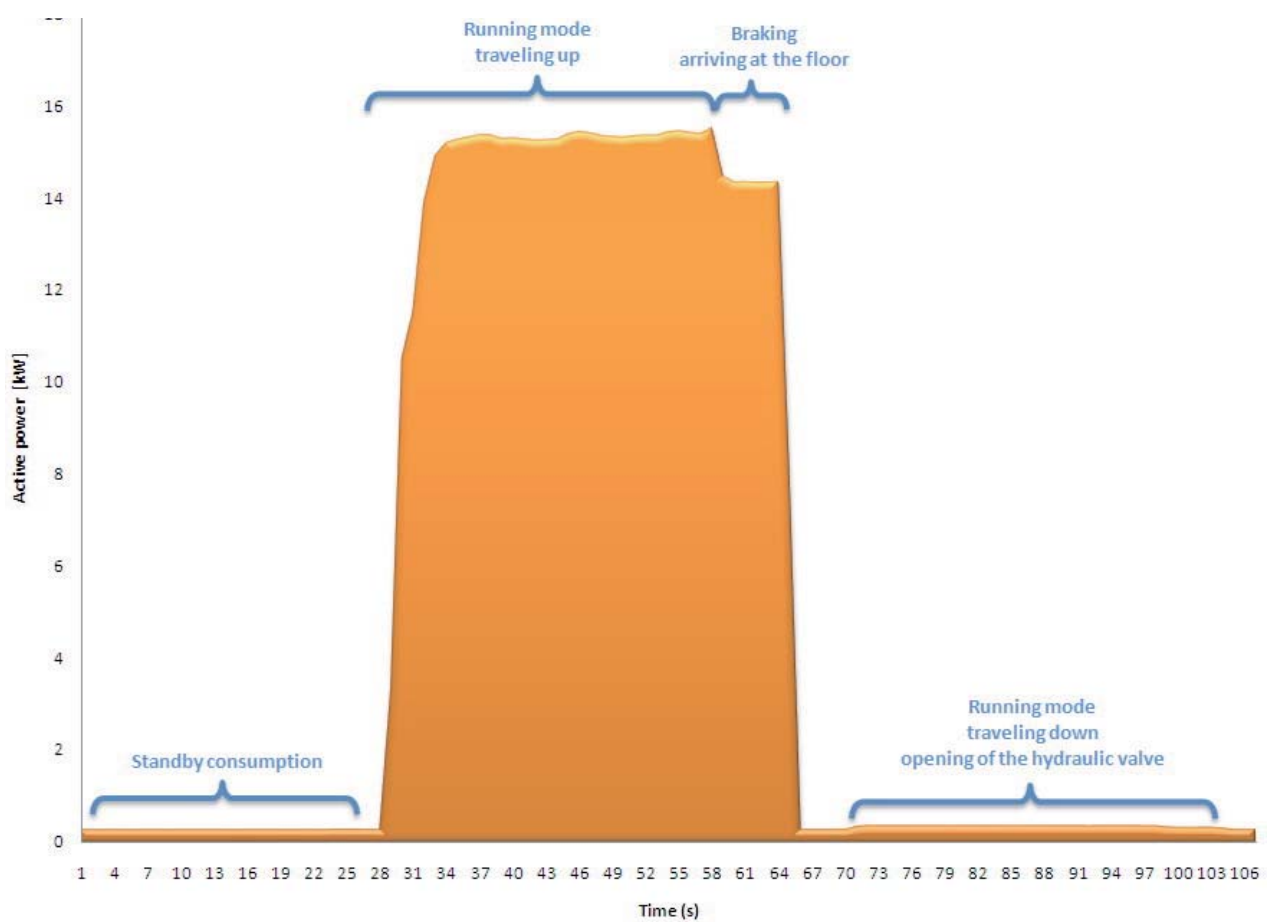


Figure 7. Typical cycle of a hydraulic elevator

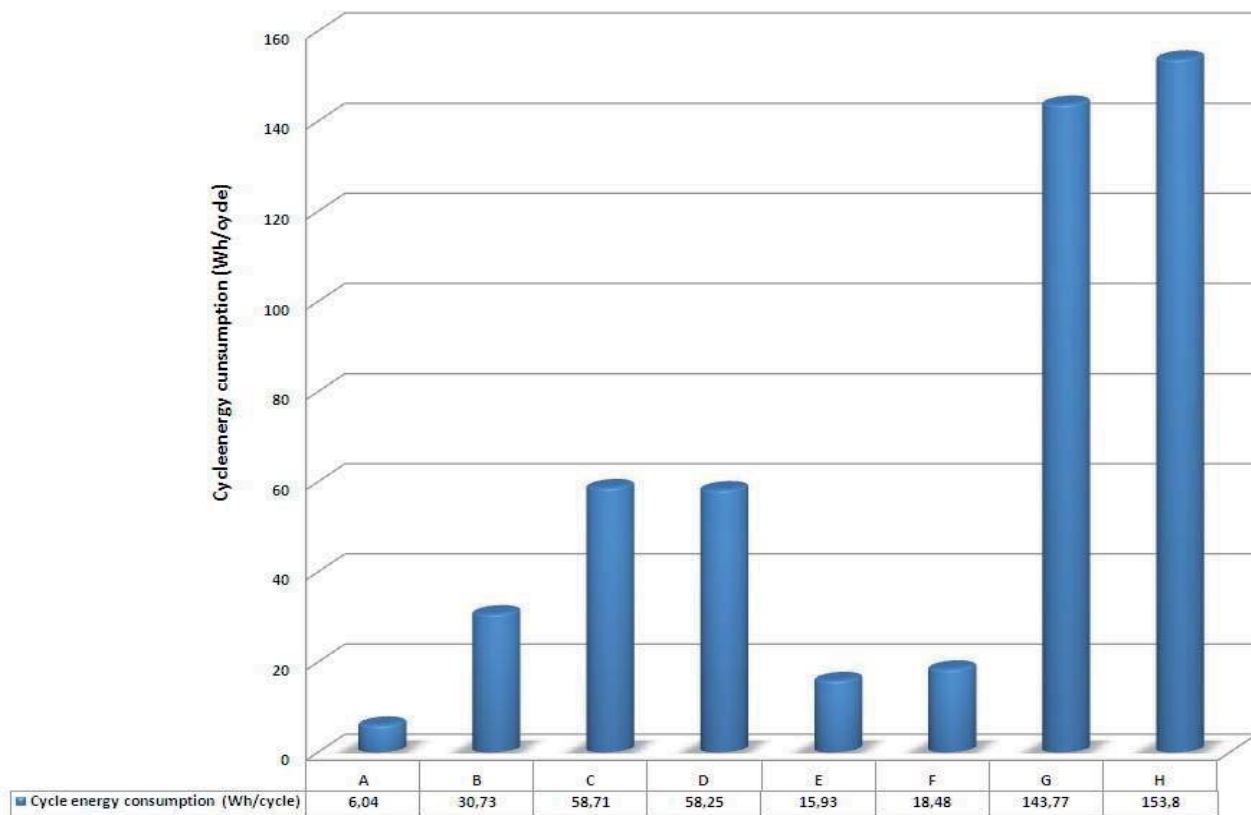


Figure 8. Travel cycle consumption of the elevators.

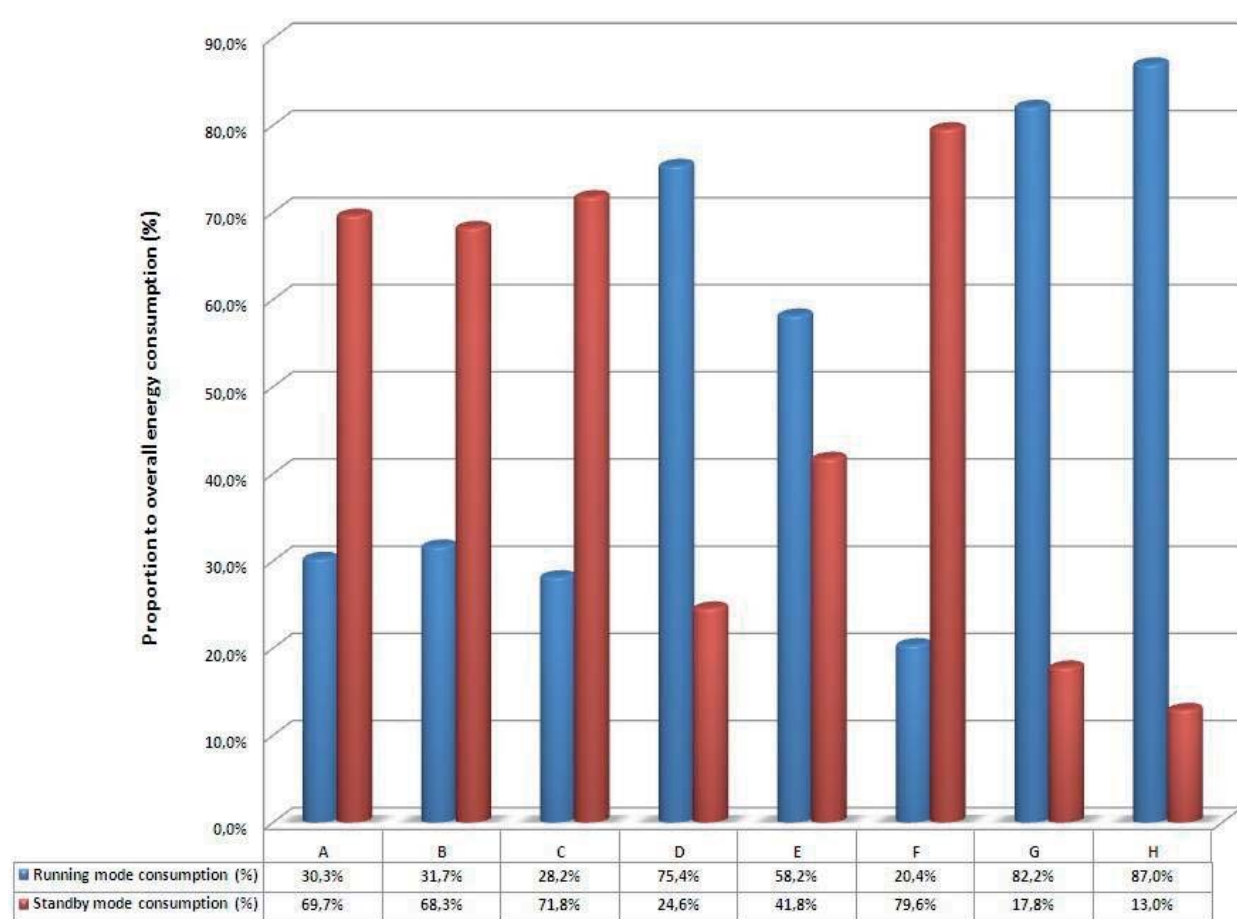


Figure 9. Proportion of standby and running mode to overall energy consumption of elevators

ESCALATORS

The figure 10 illustrates the several states of operation of an escalator.

In the figure 10, the peak consumption periods corresponding to the starting of the motor drive and acceleration period until the escalator reaches the “normal speed” mode are clear. After some time without activity, escalators reduce their speed and reach the so called “low-speed” mode. The consumption in this “low-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 there are some components of the system that are not totally switched off, such as the lighting, control systems, movement sensors, etc.

Standby energy consumption

The figure 11 presents the standby consumption and the running mode consumption, in proportion to the overall consumption of the escalators analysed.

In the escalators analysed the active power in low-speed mode goes from 450 W to 960 W and in stop mode from 42 W to 60 W. Since the standby consumption is considered to be the sum between the low-speed mode and the stop mode consumption, standby consumption in escalators is around 14.3% to 23.4% of the total overall energy consumption.

Conclusions

Although only preliminary results of the E4 Project are presented in this paper, it is evident that the choice of technology used in elevators or in escalators can yield significant differences in the energy consumption of such systems and that their energy efficiency can be greatly improved.

Notably, the reduction in standby energy consumption presents itself as an opportunity that cannot be disregarded. The measured consumption in standby mode in elevators represents 24.6% to 79.6% of the overall consumption. In escalators this percentage goes from 14.3% to 23.4%.

When improving the energy efficiency of elevator and escalators two approaches are considered: conceptual and functional. This means that it is not sufficient to consider energy efficient components (e.g. motors and drives, lighting, power supplies, etc) at the design phase, but also to take into account the way they are used. There are certain components or systems in elevators and escalators that after each travel can be switched off or partially switched off, like for example: car lighting, car fans, call buttons, displays, etc. The way the control system is managed also directly affects the energy consumption of the drive. For example, the correct choice of travel speed, acceleration and jerk can be optimized for both adequate servicing and energy efficiency.

Most of the building owners contacted during the monitoring campaign were not fully aware of the technical achievable solutions for energy savings on elevator installations and its impact on the overall energy costs of the building. It is predict-

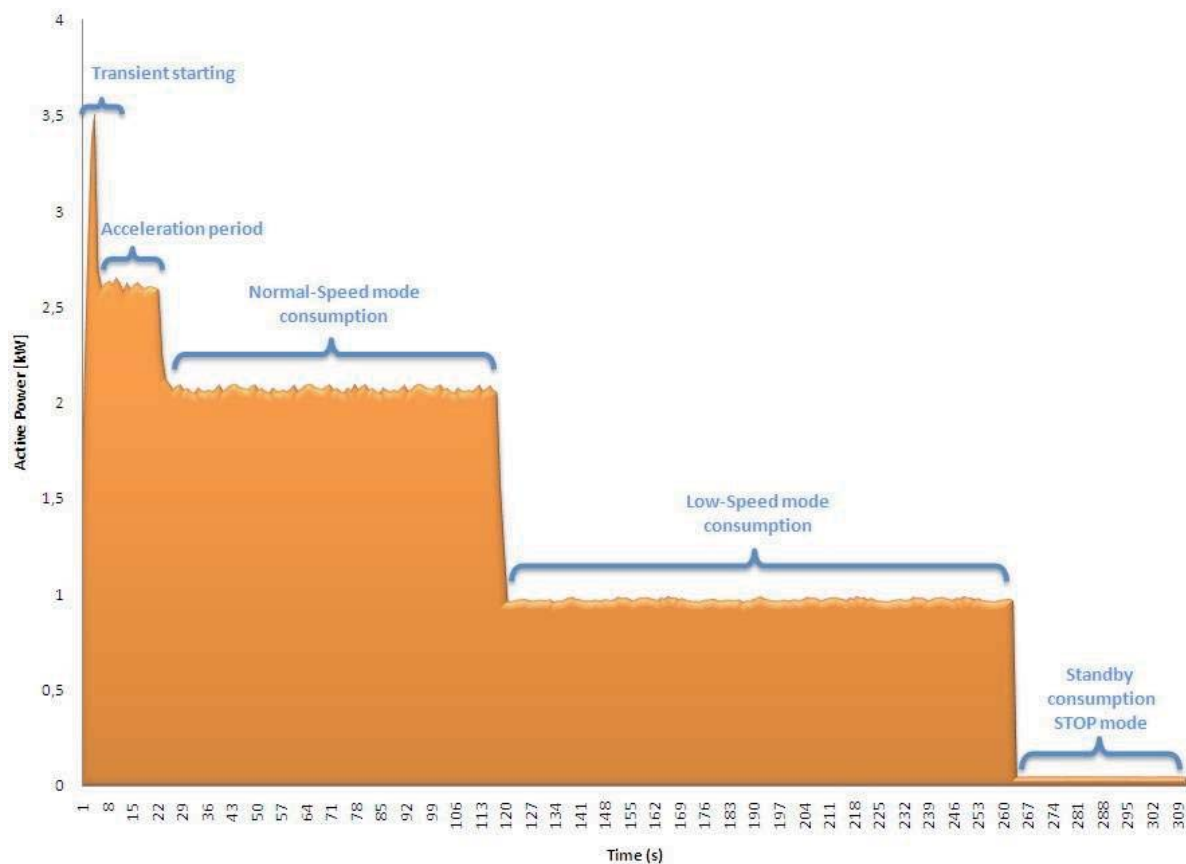


Figure 10. Active power of an escalator in different operation modes

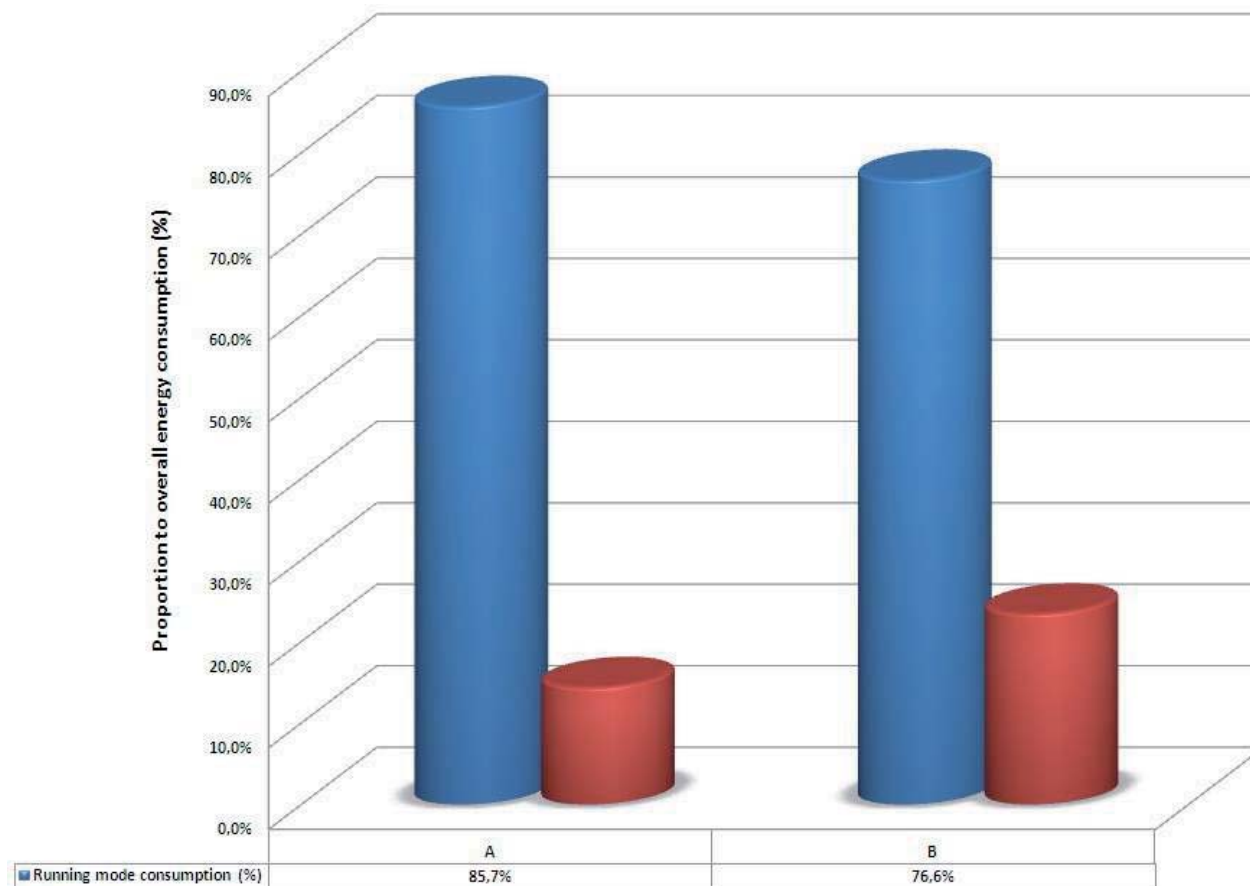


Figure 11. Proportion of standby and running mode to overall energy consumption of escalators.

able that this misinformation is generalized and a major barrier to the penetration of these more energy efficient solutions. Elevator associations and manufacturers should contribute to sensitize the market.

Bibliography

- [De Almeida, A. et al, 2005] De Almeida, A.; Ferreira, F.; Both, D.: “Technical and Economical Considerations to Improve the Penetration of Variable Speed Drives for Electric Motor Systems,” IEEE Transactions on Industry Applications, January/February 2005
- [Çelik and Korbahti, 2006] Çelik, Ferhat and Korbahti, Banu, “Why hydraulic elevators are so popular”, Elevator World, April 2006
- [EN 60359, 2002] EN 60359:2002 Electrical and electronic measurement equipment - Expression of the performance
- [Enermodal, 2004] “Market Assessment for Energy Efficient Elevators and Escalators”, Final Report, Prepared for the Office of Energy Efficiency and Natural Resources of Ottawa by Enermodal Engineering Limited, Canada, September 2004
- [Sachs, 2005] Harvey M. Sachs, “Opportunities for elevator energy efficiency improvements”, ACEEE, April 2005
- [Gemici, 2005] E. Gemici, “European Statistics of the Lift Industry” Presentation, 9th International Lift Technology & by-industries Fair, 15 April 2005, Istanbul

- [Gemici, 2006] E. Gemici, “European Statistics of the Lift Industry” Presentation, General Assembly 2006
- [Gharibaani, 2008] Gharibaani Esfandiar, Load Factor for Escalators, EG (09/05/2008).
- [CIBSE, 2008] “CIBSE Guide D: Transportation systems in buildings”, The Chartered Institution of Building Services Engineers London, September 2005, Reprinted with corrections in July 2008
- [ISO/DIS 25745-1, 2008] Draft International Standard ISO/DIS 25745-1 Energy Performance of Lifts and Escalators – Part 1: Energy Measurement and conformance, 2008
- [Lindegger, 2008] Lindegger Urs, Energy estimation: Document for E4, ELA, VDI & ISO, 11 June 2008
- [Nipkow and Schalcher, 2006] Jürg Nipkow and Max Schalcher, “Energy consumption and efficiency potentials of lifts”, S.A.F.E. (Swiss agency for efficient energy), EEDAL 2006
- [Strakosch, 1983] Strakosch, George R., “Vertical Transportation, Elevators and Escalators”, New York: John Wiley & Sons, 1983

Acknowledgments

The E4 Project was mainly supported by the European Commission, Executive Agency for Competitiveness and Innovation, EACI.