

Intelligent Vertical Mobility In Sustainable Urban Environments

Alejandro Becerro Casadomet

Research Scholar, Industrial Engineering, Faculty of Engineering, Kennedy University, France.

Dr. Ignacio Bonasa Alzuria

Thesis, Supervisor, Spain.

Email: alejandrobece7@gmail.com

Abstract

The rapid growth of urban populations and increasing pressure on existing infrastructure have created a need for intelligent and sustainable mobility solutions. Vertical mobility, including elevators, escalators, and smart building transportation systems, plays an important role in improving accessibility, reducing congestion, and enhancing the efficient movement of people within high-rise buildings and densely populated urban environments. This paper explores the integration of intelligent technologies into vertical mobility systems to support sustainable urban development. By incorporating the Internet of Things (IoT), artificial intelligence (AI), machine learning, and real-time data analytics, smart vertical transportation can optimize traffic flow, reduce waiting times, improve energy efficiency, and enhance passenger safety. Predictive maintenance and intelligent control strategies can further reduce operational costs, equipment downtime, and unnecessary energy consumption. The study also highlights the importance of integrating vertical mobility with smart-city infrastructure, renewable energy systems, and accessible building design. Key challenges include implementation costs, cybersecurity, system interoperability, and the need for reliable real-time data. Intelligent vertical mobility offers opportunities to improve transportation efficiency and contribute to more inclusive, resilient, and environmentally sustainable urban environments.

Keywords— Intelligent Vertical Mobility, Sustainable Urban Mobility, Smart Elevators, Internet Of Things (IoT), Artificial Intelligence, Energy Efficiency, Predictive Maintenance, Smart Buildings, Urban Sustainability, Intelligent Transportation Systems.

Introduction

1.1 Objectives

The main objective of this project is to develop an energy-efficient and material-conscious rehabilitation strategy for an existing residential building through the integration of an elevator. The study focuses on establishing the technical need for elevator installation, examining the structural relationship between the existing and proposed elements, optimizing construction materials, and evaluating the eco-efficiency of the rehabilitation process. In

addition, the project considers the basic electrical requirements of the elevator system and analyses residential traffic to determine suitable elevator characteristics. The work combines elevator installation, construction-material optimization, eco-efficiency assessment, and traffic analysis into a unified rehabilitation approach. This integrated methodology provides a broader perspective for improving accessibility and energy performance in existing residential buildings.

Received: 11-07-2026

Revised: 21-08-2026

Accepted: 08-09-2026

Published: 25-09-2026

Citation: “ Intelligent Vertical Mobility In Sustainable Urban Environments”, *ijaicn*, vol. 2, no. 3, pp. 141–160, September. 2026,

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1.2 Justification and Feasibility

Accessibility, environmental sustainability, and social inclusion are increasingly important in the modernization of existing buildings. Although modern residential buildings generally provide improved accessibility, many older multi-storey buildings still lack elevators and therefore create difficulties for elderly people, individuals with disabilities, and residents with limited mobility. Installing an elevator can significantly improve vertical accessibility; however, its integration into an existing structure requires careful consideration of available space, structural conditions, staircases, corridors, entrances, and other building elements. This project therefore investigates suitable technical solutions for incorporating an elevator while maintaining functional circulation and reducing unnecessary construction work. Energy consumption is also considered through the assessment of elevator motors, lighting, control systems, standby operation, and energy-regeneration technologies. Traffic analysis is included to relate expected passenger demand to elevator capacity and operating requirements. The practical feasibility of the proposed approach is supported by its potential application to existing residential buildings where architectural barriers, structural limitations, or the absence of vertical transportation restrict accessibility.

1.3 Development of the Project

The study is organized to examine the rehabilitation problem from theoretical, technical, environmental, and practical perspectives. The initial sections introduce elevator technology, its historical development, operating principles, and major types, with particular attention to machine-room-less systems and their suitability for existing buildings. The main elevator components are then examined to support the selection of an appropriate configuration. The subsequent analysis focuses on eco-efficiency and energy consumption, considering factors such as motor technology, lighting, intelligent controls, automatic shutdown, and regenerative energy systems. The energy performance of the selected system is also examined using the VDI 4707 classification approach. Construction alternatives are then evaluated according to structural compatibility, material requirements, space limitations, and overall feasibility, allowing an appropriate rehabilitation solution to be identified. Finally, elevator traffic analysis is applied to the residential building using theoretical and computational methods. The resulting passenger-demand characteristics are used to support the selection of elevator capacity and motor requirements. Through the combined consideration of accessibility, construction materials, energy efficiency, electrical

requirements, and traffic performance, the project develops an integrated approach for the rehabilitation of existing residential buildings.

Elevators: History, Evolution And Innovation

2.1 History

The development of elevators began with simple lifting mechanisms such as rollers, inclined planes, boards, and pulleys used in ancient construction. The invention of the wheel further improved lifting and transportation systems, while the Greeks later developed the block-and-tackle pulley system to reduce the force required to raise heavy loads. During the Greco-Roman period, compound pulleys, levers, inclined planes, and other mechanical principles significantly advanced lifting technology. Archimedes contributed important principles related to force multiplication and mechanical advantage. The Romans also used lifting platforms in structures such as the Colosseum to transport gladiators and animals. Similar lifting mechanisms continued to develop during the medieval period, including systems based on counterweights, waterwheels, ropes, gears, and animal power.



Fig: 1 - Construction of the pyramids in Egypt

During the Renaissance, Leonardo da Vinci developed mechanical lifting concepts, including a mobile crane for handling heavy construction materials. Later, mining industries introduced more advanced lifting equipment using gears, chains, and animal-powered mechanisms. In the eighteenth and nineteenth centuries, elevator technology progressed rapidly. An early manually operated elevator was installed at the Palace of Versailles in 1743, followed by the development of mechanically powered lifting systems during the Industrial Revolution. Steam-powered elevators became common in factories, while hydraulic elevator technology was introduced in the nineteenth century. The development of freight lifts further increased the practical use of vertical transportation.

A major milestone was achieved by Elisha Graves Otis, who introduced an elevator safety mechanism

designed to prevent the car from falling if the supporting cable failed. His safety elevator was publicly demonstrated in 1853 and contributed significantly to the development of passenger elevators. In 1857, the first mechanically driven passenger elevator was installed at E. V. Haughwout & Company in New York. Hydraulic elevator technology also advanced during this period, providing smooth movement, accurate stopping, and reliable operation, although early systems required substantial pumping equipment and water consumption.

The introduction of electric motors represented another major stage in elevator development. Electric elevators using drums, gears, and traction mechanisms gradually replaced many earlier steam and hydraulic systems. Automatic call buttons and push-button controls were subsequently introduced, improving convenience and reducing dependence on operators. In the early twentieth century, gearless elevators and improved speed-control systems increased elevator performance, reliability, and stopping accuracy. Automatic passenger doors were later introduced, further improving safety and usability.

From the middle of the twentieth century, electronic control systems transformed elevator operation. These systems enabled the automatic registration and management of calls and allowed multiple elevators to operate more efficiently as groups. Programmable control systems were subsequently introduced by major elevator manufacturers, while variable-frequency control technology improved high-speed operation and reduced energy consumption. Linear-motor technology and compact drive systems eventually contributed to the development of machine-room-less elevators. In 1996, Kone introduced a commercially viable machine-room-less elevator, providing significant space and installation advantages for modern buildings.

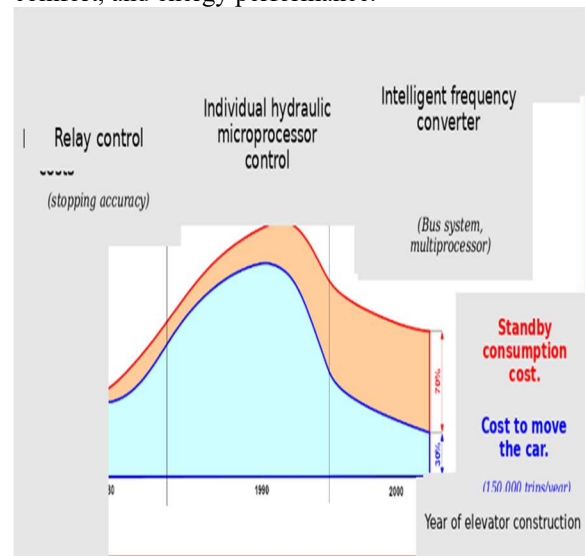
Modern elevators incorporate advanced electric drives, permanent-magnet motors, microprocessor-based controls, variable-frequency systems, intelligent traffic management, and improved safety mechanisms. These developments have resulted in higher speeds, smoother travel, more accurate floor levelling, shorter waiting times, improved energy performance, and greater operational reliability. Machine-room-less systems have also become particularly important for applications where available building space is limited. The continuing evolution of elevator technology demonstrates a transition from simple mechanical lifting devices to highly automated and energy-efficient vertical transportation systems.



Fig: 2 - Modern elevator

2.2 Evolution

Elevator technology has developed considerably through improvements in mechanical components, control systems, and energy management. Earlier elevators generally operated at one or two speeds, whereas modern systems incorporate advanced technologies designed to improve performance and reduce electricity consumption. A significant portion of elevator energy use can occur during standby operation, making intelligent control, efficient components, and energy-saving technologies important for reducing overall consumption. Continuous technological development has therefore focused on improving operating efficiency, reliability, comfort, and energy performance.



Graph - Evolution of savings in electrical consumption (translated from German)

The development of elevator regulations in Spain has been influenced mainly by the establishment of the Autonomous Communities and Spain's integration into the European Union. Initially, elevator requirements were established nationally by the Ministry of Industry. With the transfer of powers to the Autonomous Communities, additional regional requirements were introduced to complement national regulations and strengthen safety provisions. Spain's accession to the European Union subsequently required national legislation to be harmonized with European requirements through the implementation of relevant European directives. Consequently, elevator installations must comply with applicable national regulations together with the requirements established by the corresponding Autonomous Community.

The regulatory framework has evolved through several important stages. The first lifting equipment regulations appeared in 1952 and introduced basic safety requirements, including provisions concerning elevator car doors. These regulations were replaced by the 1966 regulations, which incorporated additional technical requirements. Further safety measures were introduced during the 1970s and 1980s, including the restoration of mandatory car doors and technical requirements for older elevators. Royal Decree 2291/1985 subsequently expanded the regulatory scope to cover various lifting and transport equipment, including elevators, escalators, lifting platforms, cranes, and other related systems.

A major regulatory development occurred with Royal Decree 1314/1997, which implemented European Directive 95/16/EC concerning lifts. Applicable to elevators installed after July 1999, it brought Spanish requirements closer to those of other European Union Member States and introduced a framework based on conformity with established safety standards. Subsequent amendments incorporated technical developments and European requirements for both electric and hydraulic elevators. The current regulatory framework also established provisions for installation, modification, maintenance, inspection, registration, and commissioning of elevator systems. Royal Decree 88/2013 introduced further provisions through the ITC AEM-1 for elevators. The regulation applies to newly installed elevators and modifications, while existing elevators are subject to specific requirements concerning maintenance, major modifications, and inspections. Procedures for commissioning require relevant technical documentation, conformity declarations, inspection reports, and maintenance arrangements. The framework also establishes maintenance intervals according to the type and use of the elevator and

specifies response requirements for faults and emergency situations.

The regulatory framework also defines requirements for elevator maintenance companies and technicians. Maintenance organizations must satisfy specified technical and professional requirements, while elevator maintenance technicians must demonstrate appropriate qualifications through academic education, vocational training, professional certification, or recognized work experience. Major elevator modifications are subject to defined conformity procedures, and inspection bodies may be required to participate in the certification process. Periodic inspection requirements are also established to maintain safe operation throughout the elevator's service life.

Safety standards form an additional component of elevator regulation. EN 81-1 establishes safety requirements for the construction and installation of electric lifts and is associated with the wider European and international standardization framework for lifting equipment. Other standards and provisions, including ISO 4190 and European Directive 95/16/EC, address the selection, planning, installation, and safety of passenger and freight elevators. Together, these regulatory and technical standards have contributed to the progressive improvement of elevator safety, reliability, energy efficiency, and operational performance.

2.3 Innovation in Elevators

Modern elevators increasingly use gearless traction, compact drives, intelligent controls, and energy-efficient components. These developments reduce weight, energy consumption, space requirements, and installation time. Current research also focuses on computer-based technologies such as fuzzy logic and artificial intelligence.

Self-Propelled Elevator

A self-propelled elevator uses an independently moving car with its propulsion system beneath the car, eliminating the need for a conventional machine room. Guide columns, friction rollers, frequency control, microprocessor control, and automatic safety systems are integrated into the structure. The design offers reduced space requirements, easier maintenance, lower noise and energy use, and simplified installation, making it suitable for existing buildings. The Schindler Mobile 630 has a capacity of 630 kg, accommodates eight passengers, and operates at 0.63 m/s.

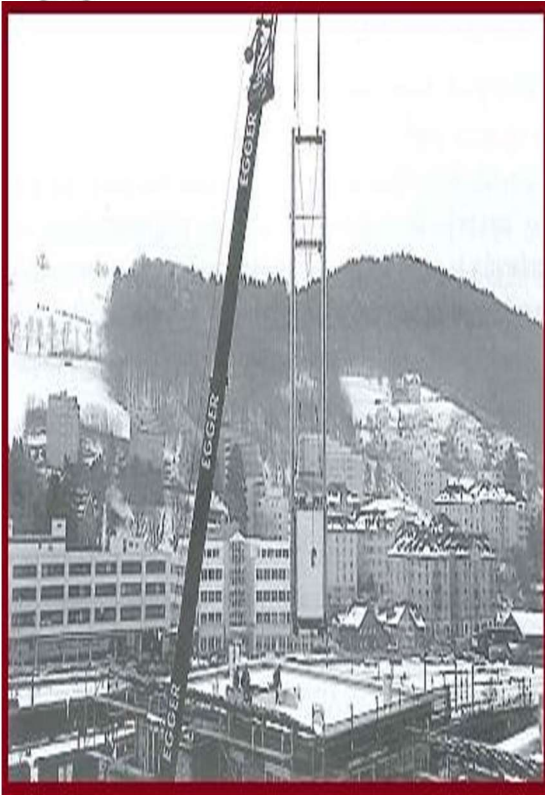


Fig: 3 - Schindler Mobile self-propelled elevator

Permanent-Magnet Synchronous Motor

Permanent-magnet synchronous motors provide high efficiency, low energy consumption, and compact construction. Their traction system can be integrated within the shaft, eliminating the machine room. The EcoDisc system developed by KONE is an example of this machine-room-less elevator technology.

Linear Motors

Linear motors are investigated for high-rise and space-limited buildings because they can eliminate suspension ropes and reduce machinery space. Their advantages include lower mechanical losses, reduced rope wear, and improved efficiency. However, high cost, thermal problems, stability issues, dust sensitivity, and maintenance difficulties remain significant limitations.

EcoDisc and MonoSpace

Research into compact elevator drives led to flat axial motors that can be integrated into the counterweight. Among the studied motor types, permanent-magnet motors provide smaller dimensions, higher efficiency, and better power factor, although their cost is higher. With no reduction gear or hydraulic pump, these machines can achieve approximately 75–85% efficiency. Frequency converters and dedicated control systems are used for effective motor operation.

2.4 Innovation in Materials

Recent material research in elevator technology focuses on reducing weight, cost, and energy consumption while improving component performance. Aramid ropes and carbon-fibre structures are among the major materials being investigated for future elevator applications.

Aramid Ropes

Aramid fibres are synthetic aromatic polyamides known for their high tensile strength, stiffness, impact resistance, and thermal stability. They are produced through extrusion and spinning processes and are available in different grades with varying stiffness and mechanical properties. Compared with conventional steel ropes, aramid ropes offer significantly lower weight, high tensile strength, corrosion resistance, longer service life, and reduced maintenance requirements. Their smaller required traction-sheave diameter also helps reduce installation space. These characteristics make aramid ropes suitable for lightweight elevator systems and high-rise applications.

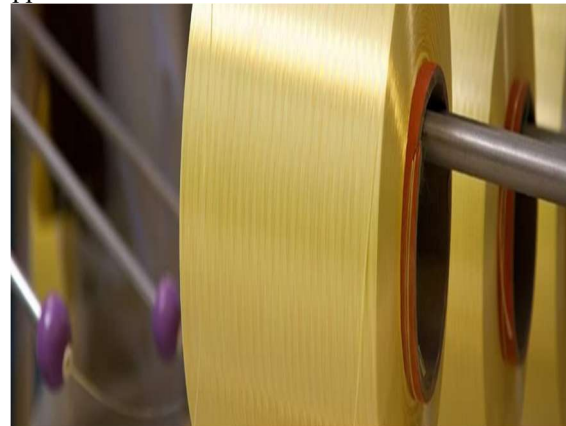


Fig: 4 - Reels of aramid yarn

Carbon Fibres for Frames

Carbon fibre is a lightweight, high-performance material increasingly studied for elevator frames and car structures. It provides high specific strength and stiffness, low thermal expansion, excellent fatigue resistance, corrosion resistance, and good dimensional stability. Carbon fibres are commonly produced from precursors such as polyacrylonitrile (PAN) and pitch through processes including stabilisation, carbonisation, graphitisation, and surface treatment. Their low density enables substantial structural weight reduction compared with conventional materials.

Carbon-fibre elevator structures have shown promising mechanical performance in prototypes and experimental studies. However, high manufacturing cost, fire behaviour, impact resistance, and possible galvanic corrosion when combined with metals remain important considerations. Further research is therefore

required before widespread structural application in elevators.

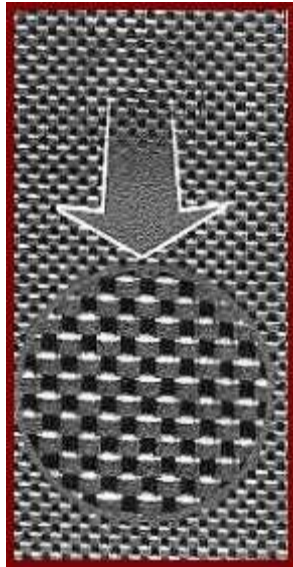


Fig: 5 - Carbon-fibre fabric suitable for use in elevator frames

2.5 Practical Application

Rapid technological development in elevator systems has introduced innovations that have required changes in standards and regulations. A major example is the elimination of the conventional machine room. In 1996, KONE introduced the first machine-room-less elevator, creating a new approach to elevator installation and leading to regulatory review. In Spain, the Ministry of Industry and Energy authorised the installation of machine-room-less elevators through the Resolution of 3 April 1996 issued by the Directorate-General for Industrial Technology and Safety. This decision supported the practical implementation of the new technology within the national regulatory framework.

Types Of Elevators And Their Components

3.1 Types of Elevators

Elevators are broadly classified into **hydraulic and electric traction systems**. Other specialised lifting systems include freight lifts, bed or stretcher lifts, car lifts, dumbwaiters, and lifting platforms. Freight lifts are designed mainly for transporting materials and heavy loads, while bed lifts provide smooth and reliable transportation of patients and stretchers in healthcare facilities. Car lifts transport vehicles in multi-level parking and storage facilities and generally operate at low speeds. Dumbwaiters are small freight lifts commonly used in hotels and restaurants. Lifting platforms are used to raise people, tools, or materials

to different working heights and are widely applied in industrial environments.

3.1.1 Hydraulic Elevator

A hydraulic elevator moves the car using a piston powered by pressurised oil. Its main components are the electric motor, pump, valve system, oil tank, cylinder, and piston. Compared with electric traction elevators, hydraulic systems generally have lower speeds, higher installation and power requirements, and are more suitable for buildings with limited height. However, they can handle heavy loads effectively and transfer the load directly to the building foundations, making them useful in some existing or older buildings. Their valve system also provides accurate stopping and levelling, while emergency lowering can allow passengers to exit during power failure.

Hydraulic elevators may use **direct (1:1) or differential (1:2) drive**. In direct drive, the car moves the same distance as the piston and is suitable for shorter travel distances and higher loads. Differential drive uses a pulley and rope arrangement, allowing the car to travel twice the piston distance and making it suitable for longer travel. Pistons may be simple or telescopic; telescopic pistons provide greater travel with reduced cylinder length but involve higher complexity, cost, friction, and leakage risk. The selection of a hydraulic system depends mainly on the required load, travel distance, speed, and number of stops.

3.1.2 Electric Elevator

Electric elevators use a traction system in which an electric motor drives a traction sheave that moves the ropes supporting the car and counterweight. Modern systems generally use AC motors with one or two speeds or frequency converters, while older DC-based systems may also be used. The main circuits include the **traction system**, consisting of the motor, brake, reduction gear and traction sheave; the **lifting system**, consisting of the car, counterweight and ropes; and the **speed-limiting and safety system**, which includes the overspeed governor and safety gear. Guide rails, buffers, pulleys, landing doors, and associated fixed equipment complete the elevator installation.

3.2 Elevator Components

An elevator is a mechanical system used to transport people and goods between different levels of a building. It combines electrical, mechanical, and electronic components to provide controlled and safe vertical movement. The main elements are the **car, counterweight, suspension ropes and traction unit, and control equipment**. The elevator installation is designed according to applicable safety and accessibility requirements.

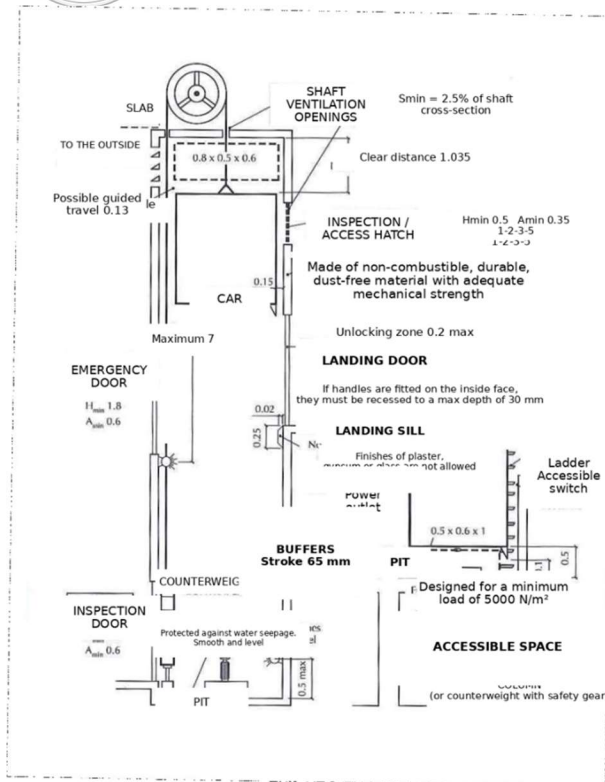


Fig: 6 – Dimensions and profile of an elevator

Elevator Shaft

The elevator shaft is the enclosed space through which the car and counterweight travel. It is formed by the shaft walls, pit, and ceiling and is reserved exclusively for elevator equipment. The enclosure must have sufficient structural strength to withstand loads from the guide rails, safety gear, and other components. Where required, the shaft must include suitable ventilation and fixed lighting, with the source specifying approximately 1% of the shaft cross-sectional area for ventilation and 50 lux at specified locations for lighting.

The shaft includes the **pit and headroom**. The pit is located below the lowest landing and contains the buffers, guide components, and drainage arrangements. Buffers reduce the effects of excessive downward movement and provide protection if normal stopping systems fail. Adequate clearance must also be maintained beneath the car. The counterweight must remain within the elevator shaft and must be suitably protected throughout its travel.

Elevator Car

The elevator car is the load-bearing enclosure used to transport passengers or goods. It consists mainly of the **car frame and car enclosure** and may be designed as a conventional or panoramic car. The car must provide adequate internal height, structural strength, ventilation, lighting, and emergency communication.

The specified lighting requirement is at least 50 lux at floor level and near the controls, with emergency lighting available during power failure.

Car Frame

The car frame or chassis supports the car enclosure and provides attachment points for the suspension ropes and safety gear. It must be sufficiently strong to withstand normal operating loads and the forces generated when the safety gear is activated. Its main components include uprights, guide shoes, cross-members, bearings, wedge mechanisms, supports, and rope fixing arrangements.

Car Enclosure

The car enclosure forms the passenger or load compartment and is fixed to the frame. It is constructed with solid walls, floor, and roof, with suitable openings only for doors, ventilation, and emergency access. The enclosure must withstand the required mechanical loads without excessive deformation. Its dimensions and capacity are selected according to the rated load and accessibility requirements. Modern lightweight materials and prefabricated sandwich panels can reduce car weight while maintaining adequate strength, thereby improving elevator efficiency.

Car and Landing Doors

Elevator doors provide controlled access to the car and shaft and are essential for passenger safety. Modern elevators use solid car and landing doors equipped with mechanical locks and electrical safety controls. Automatic doors are commonly operated by an electric motor and may use side or central opening arrangements. The selected system in this project uses **two-panel, left-side-opening automatic doors** with an 800 mm clear passage and 2,000 mm height.

Door safety is provided through locking mechanisms, electrical interlocks, photoelectric sensors or light curtains, and sensitive edges that prevent the doors from closing when an obstruction is detected. Landing doors are operated through the car-door coupling mechanism and may be manufactured from metal, glass, or glazed panels. Depending on the application, doors may also be hinged, sliding, manual, semi-automatic, or automatic.

3.3 Safety Standards for Users

Elevator safety depends on proper user awareness and responsible operation. Users should never use elevators during fires, earthquakes, or when water enters the shaft, and must not exceed the rated load or passenger capacity. Jumping, sudden movements, unnecessary calls, tampering with controls, or misuse of emergency and stop buttons should be avoided. Doors must not be forced open or used to stop the elevator, and passengers should remain inside the car if it stops between floors, using the emergency

communication system and waiting for qualified maintenance personnel. Children should not travel alone and must be kept away from the doors. Users should also avoid throwing waste or cigarette ends into the shaft, switching off car lighting, or repeatedly pressing registered call buttons. Machine components and control panels must never be accessed by passengers, and normal travel and waiting times should be observed patiently.

3.4 Types of Control Systems

Elevator control systems coordinate car movement and floor calls according to building traffic requirements. **Universal control** is the simplest and least expensive system, allowing one passenger or group to control the car at a time. It is suitable for low-rise residential buildings with low traffic, but may cause unnecessary trips, higher energy consumption, and increased wear.

Down collective-selective control is commonly used in residential buildings and hotels with relatively low inter-floor traffic. Similar to universal control, it registers calls while allowing passengers travelling downward to be collected during the same descent, improving service efficiency.

Collective-selective control (up and down) stores both car and landing calls and serves them according to the current direction of travel. After completing calls in one direction, the elevator changes direction to serve the remaining calls. This system is suitable for buildings with significant passenger traffic.

Group control (duplex/triplex) coordinates multiple elevators serving the same building population. A common landing call is assigned to an appropriate car, while each elevator responds to its assigned calls according to the selected operating mode.

Destination-control systems are designed for high-occupancy buildings, where passengers enter their destination floor at a common control panel and are assigned to a suitable elevator, reducing unnecessary stops, crowding, and travel time.

4. Development And Justification Of Eco-Efficiency Calculations

4.1 Introduction to Eco-Efficiency in the Elevator Sector

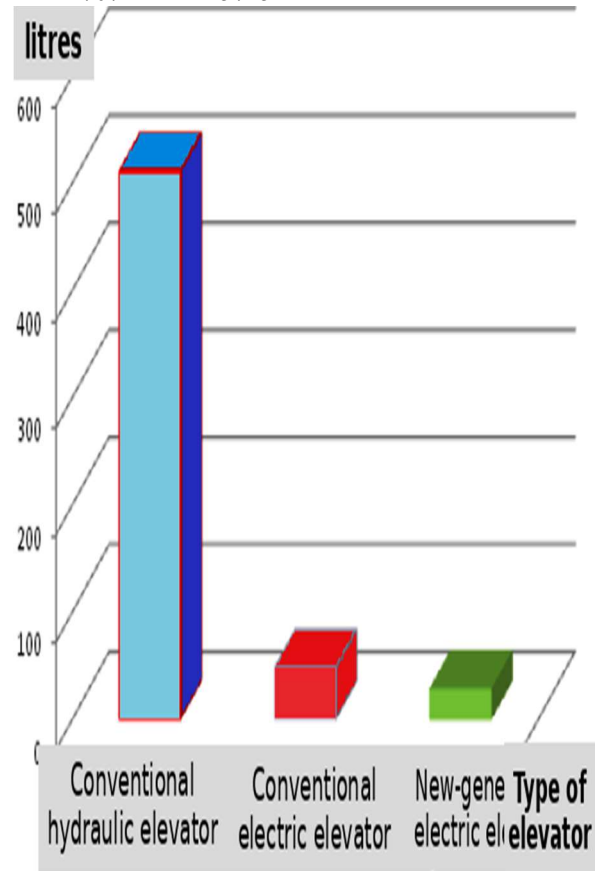
Eco-efficiency in elevators aims to reduce energy consumption while maintaining normal performance, comfort, safety, and service quality. Existing elevators can be improved through efficient components, intelligent selective controls, variable-frequency drives, gearless traction systems, and regenerative inverters. Selective controls can reduce unnecessary journeys, while frequency converters minimise high

starting consumption. Combining frequency control with gearless traction and regenerative energy recovery can further improve efficiency. Therefore, energy-efficiency measures should focus on achieving lower consumption for the same level of elevator use.

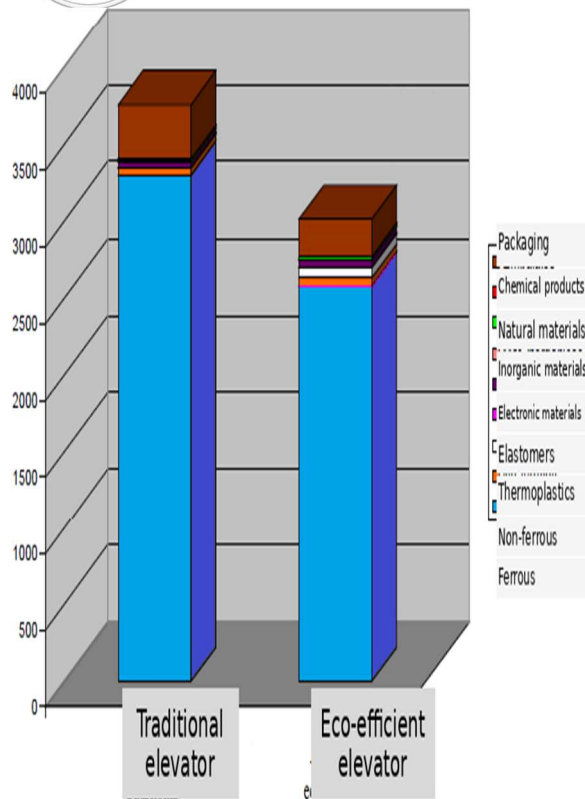
4.1.1 Environmental Impact

Elevators are significant energy-consuming equipment in buildings, with car lighting and motor operation being major contributors. Efficient elevator selection should consider building height, rated load, travel speed, operating conditions, and available installation space. Electromechanical elevators provide a wide range of load, speed, and travel capabilities, while hydraulic elevators are generally suited to low-rise applications but have higher energy consumption and travel limitations.

Important energy-saving measures include switching off car lighting during standby, using LED or other high-efficiency lighting, applying selective control systems to reduce unnecessary empty-car journeys, using speed-regulated drives, and selecting modern gearless permanent-magnet synchronous machines. Elevator efficiency can also be evaluated according to VDI 4707 or ISO 25745 classifications.



Graph - Comparison of lubricating-oil consumption



Graph - Raw materials (in kg)

Life Cycle Assessment

The environmental performance of an elevator can be assessed using Life Cycle Assessment (LCA), considering impacts from material extraction and production through manufacturing, distribution, installation, operation, maintenance, recycling, and final disposal. ISO 14040 and ISO 14044 provide the framework for LCA, while methods such as CML 2001 and Eco-indicator 99 can be used for impact assessment. The main environmental categories considered are climate change, ozone-layer depletion, acidification, eutrophication, and photochemical oxidation. Permanent-magnet traction systems can also reduce the need for lubricating oil associated with conventional reduction systems.

Environmental Profile and Resource Consumption

The environmental assessment considers raw materials, manufacturing processes, transportation, installation, operational energy consumption, maintenance materials, and end-of-life treatment. The source assessment assumes an average distribution distance of 2,000 km and considers a 25-year service life for maintenance-related impacts. Ferrous and non-ferrous metals and packaging represent most of the elevator's total mass, resulting in a high potential for material recovery and recycling.

The principal environmental indicators are **Global Warming Potential (GWP)**, which measures greenhouse-gas effects in CO₂ equivalents; **Ozone Depletion Potential (ODP)**, expressed using CFC-11 as the reference substance; **Acidification Potential (AP)**, associated mainly with emissions such as SO₂, NO_x and NH₃; **Eutrophication Potential (EP)**, related to nutrient enrichment of water systems; and **Photochemical Ozone Creation Potential (POCP)**, associated mainly with volatile organic compounds and expressed using ethylene equivalents. These indicators allow environmental impacts to be evaluated across the different stages of the elevator life cycle.

Energy Demand in Standby and Travel Modes

Elevator energy consumption is divided into **standby demand** and **travel demand**. Standby demand is measured after the elevator has remained inactive for five minutes and includes the energy required to keep the system ready for operation. Travel demand is evaluated through a reference journey involving an empty car travelling between levels, including door opening and closing operations. Considering both operating modes provides a more complete assessment of elevator energy efficiency and supports the selection of appropriate energy-saving technologies.

4.2 Description of Eco-Efficiency Calculations Applied to Elevators

Technological development and stricter energy-efficiency standards provide opportunities to reduce elevator energy consumption and environmental impact. Efficient machinery, recyclable materials, intelligent controls, and modern lighting systems can improve performance while reducing energy use. Public energy-efficiency programmes and elevator renovation schemes also encourage the replacement of outdated components with more efficient technologies. The Spanish Energy Saving and Efficiency Strategy (E4) and subsequent action plans supported measures for improving energy performance, including elevator renovation and efficient lighting.

Elevator renovation programmes implemented in several Autonomous Communities promote improvements to traction systems, car lighting, and intelligent call-management equipment. According to the source *Energy-efficient latest-generation elevators* by Carlos Jiménez Moreno, elevators may account for approximately 3–5% of building energy consumption, with older equipment showing a significant proportion of consumption associated with car lighting and traction. Replacing these high-consumption components can therefore provide substantial energy

savings. The economic evaluation should consider not only the initial quotation but also the long-term operating cost, since higher-efficiency equipment may recover its additional investment through reduced electricity consumption.

Gearless traction systems are an important energy-efficiency measure. According to the source data, replacing conventional systems in the approximately 1,025,000 elevators installed in Spain could provide energy savings of about 41% compared with conventional elevators and 68% compared with hydraulic systems. Space-efficient solutions such as double-deck and Twin elevator arrangements can also improve building circulation where appropriate, although their suitability depends on building requirements and regulations.

Energy regeneration is another important efficiency approach. During certain operating conditions, the elevator and counterweight exchange potential energy, while regenerative systems can recover excess electrical energy and either store it or return it to the electrical grid. Battery storage remains economically challenging according to the source because of the relatively high cost of storage compared with the recovered energy.

Finally, two simple measures can significantly reduce unnecessary consumption: **LED car lighting** and **standby operation** when the elevator is not in use. These measures are particularly relevant in residential buildings, where elevators remain inactive for much of the day. Combining efficient traction, intelligent control, regenerative technology, LED lighting, and standby functions provides a practical approach to reducing elevator energy consumption while maintaining normal service performance.

4.3 Selection of a New-Generation Traction Machine

The traction machine is a major contributor to elevator energy consumption, with its demand depending on the relationship between the car load and counterweight. During upward travel with a full car or downward travel with an empty car, the motor provides traction, while during opposite loading conditions it primarily performs braking. When the car and counterweight are balanced, energy losses are mainly associated with friction and machine efficiency. In conventional systems, frequency converters require significant torque during acceleration, while during deceleration the motor can operate as a generator and excess energy may be dissipated through a braking resistor.



Figure 7 - Old traction machine

Many existing elevators use squirrel-cage asynchronous motors with worm-and-wheel reduction systems. These systems can experience substantial transmission losses, while improved planetary reduction systems can provide higher efficiency, reaching approximately 85% according to the source. Correct motor sizing is also important because oversized asynchronous motors can increase active and reactive energy consumption. The **power factor ($\cos \phi$)** represents the relationship between active and apparent power, and improving it reduces reactive current, voltage drop, and losses in the electrical installation. Higher-efficiency induction motors can further reduce losses through improved materials, cooling, magnetic laminations, and reduced friction.

A more efficient alternative is the **permanent-magnet synchronous gearless traction machine**. In this system, permanent magnets mounted on the rotor generate the magnetic field, while the stator is supplied with alternating current. The motor is compact and can be installed directly within the elevator shaft, making it particularly suitable for machine-room-less elevators. Compared with conventional reduction systems, it provides higher efficiency, especially at low rotational speeds, together with smoother movement, accurate levelling, and reduced noise and vibration. The traction sheave is directly connected to the motor shaft and generally has a small diameter.

The permanent-magnet machine operates at low synchronous speed and is equipped with an **encoder and frequency converter**. The encoder continuously provides the control system with information about motor position, while the CPU processes parameters such as position, load, and braking distance. The frequency converter uses this information to regulate motor power and control acceleration and deceleration. Through this closed-loop control, the elevator achieves accurate levelling, efficient operation, and improved adaptation to changing loads.

4.4 Selection of the Elevator Car and Shaft Lighting System

Elevator lighting can represent a significant proportion of total energy consumption, particularly when car lights remain continuously switched on. Efficient lighting systems can substantially reduce this consumption. The main technologies considered are **incandescent lamps, fluorescent or low-pressure discharge lamps, and LED lighting.**

Incandescent lamps generate light by heating a filament and convert most of the consumed energy into heat. They therefore have high energy consumption and relatively short service life. Replacing them with compact fluorescent or LED lamps can provide substantial savings, while motion sensors and timers can prevent unnecessary operation when the elevator is idle.

Fluorescent lamps operate through an electrical discharge in a gas and are considerably more efficient and longer-lasting than incandescent lamps. Their performance can be improved by using modern high-efficiency tubes and electronic ballasts, which reduce electrical losses, noise, heat generation, and flicker while extending lamp life. Improved transparent ceiling panels can also increase the effective use of the available light.

LED lighting is selected as the preferred high-efficiency solution because LEDs provide high energy efficiency, long service life, low heat generation, and good resistance to vibration and impact. These characteristics make them particularly suitable for elevator cars and shafts. According to the source, LED systems can provide at least 50% energy savings compared with fluorescent or halogen lighting and can last considerably longer than conventional lighting systems. Emerging OLED panels offer further efficiency and uniform illumination, although their higher cost and shorter service life currently limit their application.

LED Lighting Energy Calculation

For the energy-saving assessment, the existing car lighting is assumed to operate continuously for **8,760 hours per year**, without automatic standby switching, allowing direct comparison with traditional lighting. Based on the project estimate of approximately **9,207,456 elevators worldwide**, an average elevator equipped with LED lighting can save approximately **500–600 kWh per year** in the absence of an energy-regeneration system. If similar LED systems were applied to all elevators considered, the potential annual saving would be approximately **5.4 billion kWh**. These calculations demonstrate the significant contribution that efficient car and shaft lighting can make to overall elevator energy reduction.



Figure 8 - Elevator car ceiling illuminated with individual LEDs.

4.5 Management Systems to Improve Eco-Efficiency in Elevator Use

4.5.1 Lighting Management System (Automatic Switch-Off)

Automatic car-lighting switch-off reduces unnecessary energy consumption by turning the lights off when the elevator is not occupied or has remained unused for a defined period. The system can be programmed to operate after approximately 1–10 minutes of inactivity and can significantly reduce lighting consumption, particularly in residential buildings where elevators remain in standby for long periods. It also extends lighting-component life and reduces maintenance requirements. According to the source, continuous lighting can consume up to approximately 650 kWh per elevator per year, while automatic switching can reduce this consumption substantially.

4.5.2 Intelligent Control Systems

Elevator controllers manage starting, stopping, direction, speed, and call allocation. Intelligent control systems use electronic controllers, microprocessors, programmable controls, speed regulation, and selective call management to match elevator operation with actual traffic demand. By avoiding unnecessary journeys and coordinating calls efficiently, such systems can reduce waiting times, equipment wear, and energy consumption. The source indicates that intelligent call-management systems can achieve electrical-energy savings of more than 10%.

Speed-regulation systems using frequency converters provide controlled acceleration and deceleration, improved low-speed operation, accurate stopping, and better passenger comfort. They also reduce high starting currents and adapt motor speed to the required torque. However, frequency converters introduce harmonics into the electrical supply, so appropriate filters, interference suppression, and shielded connections should be used to reduce

electromagnetic disturbances and comply with EMC requirements.

During braking, the elevator motor can operate as a generator and return energy to the DC bus. In conventional systems, excess energy is dissipated as heat through a braking resistor. Regenerative systems can instead recover this energy for useful applications, reducing energy losses and the associated heat load.

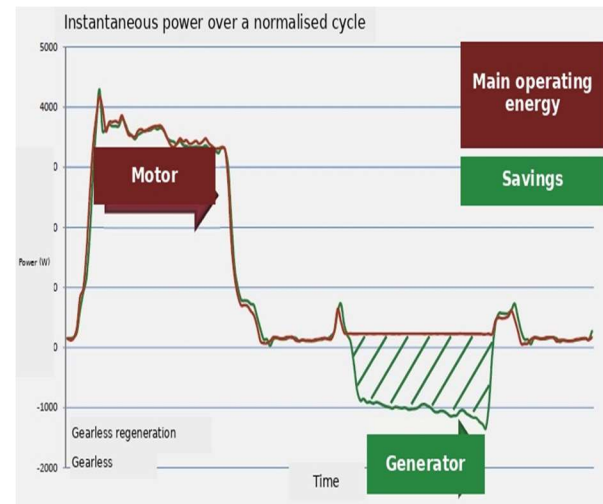
4.5.3 Energy Regeneration System

An energy-regeneration system recovers electrical energy produced when the elevator motor operates as a generator. This occurs mainly when a **lightly loaded car travels upward** or a **fully loaded car travels downward**, because the counterweight or car moves downward under gravity. The recovered energy can be supplied to the building for lighting, heating, ventilation, air conditioning, or other electrical loads. Energy storage using batteries or capacitors is also possible in principle, although the source indicates that storage may currently be economically unattractive.

According to the source, regenerative systems can provide substantial savings compared with conventional elevators, with reported savings depending on elevator load, speed, traffic, and operating conditions. When combined with permanent-magnet gearless traction machines, regeneration can further improve overall system efficiency and reduce the heat produced by braking resistors. Some systems can also support emergency operation through a UPS, allowing the elevator to move to a suitable floor during a power failure.

In a conventional elevator, braking energy is converted into heat and may increase cooling requirements. In a regenerative elevator, this energy is converted back into electricity and reused within the building, thereby reducing net electrical demand. However, actual recovery is lower than the theoretical value because mechanical, motor, and drive losses occur during both motoring and regeneration. Therefore, high overall elevator efficiency is essential to maximise the amount of energy that can be recovered.

Regenerated energy is greatest when the elevator operates far from the balanced-load condition, particularly with an empty or fully loaded car, and when the return journey involves a greater travel distance. Consequently, the effectiveness of regeneration depends on the elevator's load profile, travel distance, traffic pattern, and overall mechanical and electrical efficiency.



Graph - Regenerative drive (source: ThyssenKrupp)

5. Construction Solutions For Elevator Installation And Auxiliary Works

5.0 Calculation of Elevator Components (for Educational Purposes)

The building considered in this project is located between **30 Marcelo Fernández Nieto Street and 29 Camelas Street, Salamanca (37004)**, in the Garrido neighbourhood. The property has a total area of approximately **343 m²** and a rectangular perimeter of **75 m**. It is an older residential building without an elevator or other mechanical vertical-transport system. The proposed elevator will provide access to all floors and improve accessibility for residents.

The existing building has a **two-flight staircase**, whose current configuration and dimensions are documented in Drawing 02. The proposed elevator installation must therefore consider the existing staircase, available space and structural characteristics of the building. Figures 126–128 show the location, aerial view and surroundings of the property.

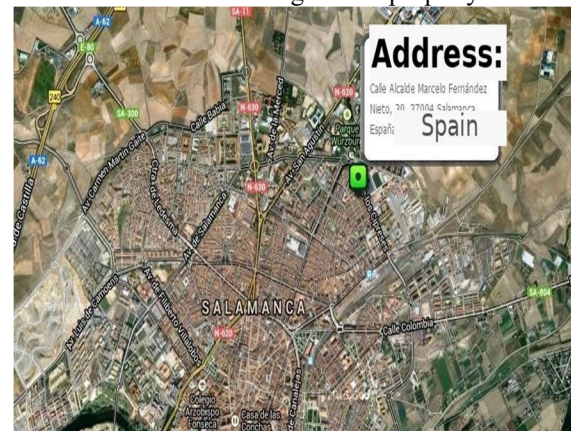


Figure 9- Map of the city of Salamanca

5.1 Reasons for Installing an Elevator

Installing an elevator significantly improves the **accessibility, comfort and usability** of a residential building. It benefits elderly residents and people with disabilities while also making everyday activities easier for families with children and for transporting heavy objects between floors. Overall, the elevator contributes to improved quality of life and enables residents to remain more comfortably in their homes.

5.1.1 Versatility and Adaptability to the Building

Modern elevator technology allows installation even where available space is limited. The appropriate solution depends on the building's staircase configuration, structural constraints and available shaft dimensions. A detailed structural-feasibility study is therefore required for each building.

Possible arrangements include installing the elevator **beside the staircase, between the staircase flights, within an extended external staircase area, or completely outside the building and attached to the façade**. Where the shaft is shallow and the pit height is limited, a **machine-room-less elevator** can provide a suitable solution while reducing construction requirements.

Elevator systems can also provide lower energy consumption and reduced environmental impact depending on their technology. In addition, the car, colours, materials and finishes can be selected to integrate the elevator with the building's existing architectural style.

5.1.2 Rapid Renovation

Modern elevator installation generally requires less construction time and causes less disruption than traditional installation methods. The work can be adapted to the building so that inconvenience to residents is minimised. The objective is to improve accessibility without adversely affecting the building's existing performance.

5.1.3 Minimum Noise

Technological improvements in elevator machinery and drive systems have significantly reduced operating noise. Modern equipment can therefore provide comfortable operation while limiting noise disturbance to residents and users.

5.1.4 Safety

Elevators incorporate several safety systems that provide reliable operation and protect passengers. Modern installations may include safety devices, telematic alarms and two-way communication systems, further improving passenger protection.

5.1.5 Comfort and Accessibility

An elevator improves everyday mobility, particularly for elderly people and people with disabilities. Modern systems provide features such as **accurate floor**

levelling, smooth stopping and suitably sized elevator cars, improving passenger comfort and ease of use. Accessibility enables people to reach, enter and use the building without unnecessary limitations caused by disability. The project also considers access requirements for emergency and firefighting situations.

5.1.6 Economic Aspects

Elevator installation represents a significant investment for building residents but can improve the property's usability and potential market value. Within the owners' association, construction costs may be distributed according to an agreed contribution system, potentially considering the greater benefit received by residents on upper floors.

Financing options may be available through elevator companies, while applicable subsidies or tax incentives may support energy-efficient installations. In the long term, efficient equipment can also reduce operating and maintenance costs and provide a favourable balance between investment, performance and service life.

5.2 Description and Justification of the Implemented Structure

Analysis of Possible Solutions

Two possible solutions were considered for the installation of the elevator and the connection between the two owners' associations. The traditional solution would involve installing two independent elevators and two separate staircases, with each owners' association developing and managing its own installation without any connection between the buildings. The second option is an innovative and efficient solution in which the two owners' associations are connected through a corridor crossing the courtyard, allowing a single staircase and a single elevator to serve both buildings. A self-supporting elevator structure is positioned adjacent to the corridor. Within this solution, two staircase configurations were considered: a single flight of 16 steps between floors, and a three-flight staircase with two 1 m landings, with six steps in each flight. The three-flight configuration was selected as the most appropriate solution.

Justification of the Adopted Solution

The selected solution complies with the applicable regulations and provides a suitable ergonomic arrangement for the building. According to the Salamanca Municipal Ordinance governing elevator installation in existing residential buildings, published in the Official Gazette of the Province of Salamanca on 25 January 2010, installations in enclosed internal courtyards must satisfy specific requirements concerning access, elevator dimensions, lighting and

ventilation, dwelling entrances, window distances, enclosure, machinery and evacuation. Elevator access must be connected to the common areas and, where possible, provide access from the entrance level and each residential floor without steps between the elevator and dwelling entrances. The ordinance does not establish specific minimum dimensions for the elevator car, shaft or access door, provided that the dimensions are adequate for proper operation.

The staircase lighting and ventilation must maintain, as far as possible, the pre-existing conditions. In front of each dwelling entrance, a clear rectangular area of approximately 1.20×1.00 m must be maintained, free from obstacles and steps. The position of courtyard windows must also be considered when locating the elevator. The shared courtyard has an area of 72.80 m^2 , while the proposed installation occupies approximately 14.88 m^2 , representing about 21% of the courtyard area. Since the distance between the elevator and the façade windows is approximately 1.65 m, the elevator enclosure must use glazed or transparent elements to maintain adequate lighting and ventilation and to prevent objects or body parts from entering the shaft. The selected elevator is machine-room-less, so a separate machine-room requirement does not affect the proposed solution. Emergency signage and lighting must also be provided where required by the Technical Building Code.

The staircase design also complies with the applicable accessibility and building regulations. According to the Technical Building Code, a single staircase flight may overcome up to 3.20 m in residential buildings where an elevator is provided as an alternative. The maximum floor-to-floor height in the building remains below this limit. In addition, the Accessibility and Barrier Removal Regulations of Castile and León, Decree 217/2001, establish a maximum of 12 consecutive steps without an intermediate landing and a minimum of three. The proposed three-flight arrangement therefore satisfies the relevant requirements while providing intermediate landings for improved accessibility and comfort.

The adopted solution also provides construction and economic benefits. A single elevator and staircase serve both owners' associations, avoiding the need to construct two separate systems. This reduces the quantity of construction materials required and lowers installation and maintenance costs. The three-flight staircase consists of 18 steps arranged as three flights of six steps, separated by two straight landings of approximately 1 m each. The staircase dimensions vary according to the different floor-to-floor heights within the building.

For the standard floors, corresponding to the second, third and fourth floors, the floor-to-floor height is 2.87 m. The complete staircase has a rise of 2.87 m and a length of approximately 7.40 m. Each flight rises 956.64 mm and contains six steps over a flight length of 1,680 mm, with a structural thickness of 100 mm and a landing length of 1,000 mm. The stringer length is approximately 1,933 mm, with a stair angle of 29.6° . Each step has a riser of 159 mm and a tread of 280 mm. The Technical Building Code criterion, $(540 \leq 2C+H \leq 700)$, gives $(540 \leq (2 \times 159) + 280 \leq 700)$, or $540 \leq 598 \leq 700$, confirming compliance. For the ground-floor staircase, the floor-to-floor height is 3.10 m, with a total staircase length of approximately 7.40 m. Each of the three flights contains six steps and has a rise of approximately 1,033.33 mm, while the flight length is 1,680 mm. The stringer length is approximately 1,972 mm, with a stair angle of 31.6° . The riser is 172 mm and the tread is 280 mm. Applying the same requirement gives $(540 \leq (2 \times 172) + 280 \leq 700)$, resulting in $540 \leq 624 \leq 700$, which satisfies the Technical Building Code. For level -1 (basement), the floor-to-floor height is 2.64 m, with a total staircase length of approximately 7.40 m. Each flight has a rise of 880 mm, six steps and a flight length of 1,680 mm. The stringer length is approximately 1,897 mm, with a stair angle of 27.7° . The riser is 147 mm and the tread is 280 mm. The dimensional check gives $(540 \leq (2 \times 147) + 280 \leq 700)$, resulting in $540 \leq 574 \leq 700$, confirming compliance. The complete dimensions and levels of the renovated staircases are provided in Drawing 04, Section of the Renovated Building.

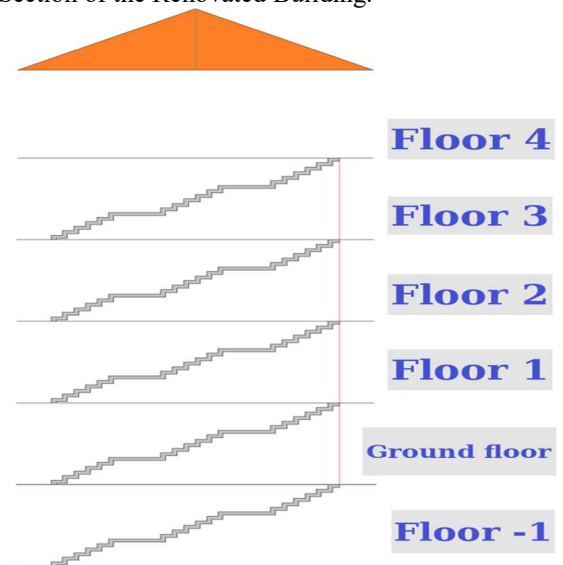


Figure 10 - Profile of the building staircases

Justification of Construction Savings

The adopted solution provides economic savings by eliminating the need for a second elevator and staircase. Based on an average elevator maintenance cost of approximately **€100 per month** and an assumed service period of **300 months (25 years)**, the maintenance cost is estimated at approximately **€30,000** over the considered period. The average construction cost of a staircase is approximately **€12,000**, giving an estimated saving of **€24,000** by eliminating one additional elevator and staircase arrangement. Therefore, the combined solution reduces construction requirements, maintenance expenditure and material consumption while providing vertical access for both owners' associations.

5.3 Infographic

The final design is represented through graphical documentation showing the selected three-flight staircase and the integrated elevator solution. The perspective view illustrates the staircase arrangement, while the final solution diagrams present the relationship between the courtyard, corridor, elevator and staircase. The building section shows the vertical arrangement of the elevator and staircase across the different floor levels, while the staircase profile provides the corresponding flight, landing, riser and tread dimensions.

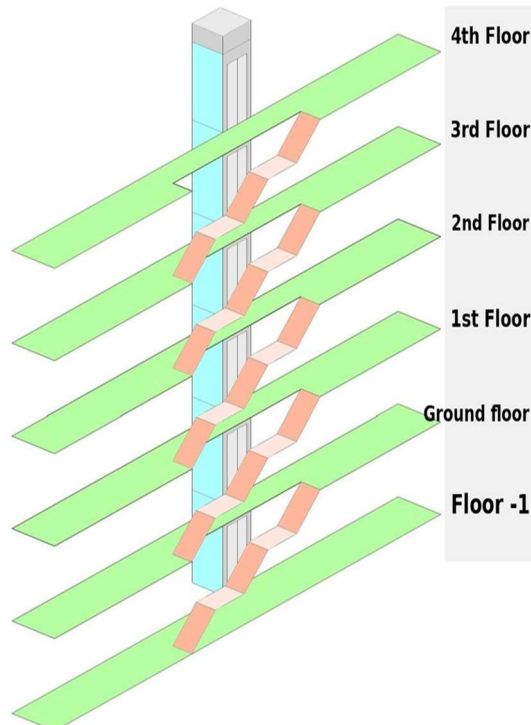


Figure 11 - Diagram of the final solution

5.4 Justification of the Electrical Installation

This section describes the sizing of the electrical supply circuit for the proposed elevator motor. The conductors, protective devices and conduits are selected according to the **Low Voltage Electrotechnical Regulations (REBT)** and their applicable Technical Instructions. The objective is to provide a suitable electrical supply for the elevator shared by the two owners' associations, each comprising four upper floors and a basement. The entrance hall and common staircase lighting will also be shared between the two associations.

Introduction and Objective

The elevator motor supply is an important circuit in the residential electrical installation because it supplies a relatively high-power motor and provides an essential vertical-transport service to both owners' associations. The objective is therefore to determine the appropriate technical characteristics and conductor sizing for safely supplying the proposed elevator motor.

Applicable Regulations and Sizing Procedure

The electrical installation is designed according to **Royal Decree 842/2002 of 2 August**, which approves the Low Voltage Electrotechnical Regulations (REBT). The principal Technical Instructions considered are **ITC-BT-19** for general requirements of indoor or receiving installations, **ITC-BT-20** for installation systems, **ITC-BT-21** for conduits and protective channels, and **ITC-BT-47** for motor-load installations. These requirements are used to determine conductor capacity, voltage drop, protective measures and installation methods.

Individual Supply Line

The individual supply line begins at the existing meter cabinet and terminates at the General Community Distribution Board located on level -1. A dedicated protective conductor is provided with the same characteristics as the active conductors and is identified in green/yellow; shared neutral or protective conductors are not used. The installation uses single-core copper conductors rated at **450/750 V**, flame-retardant and low-smoke, installed in plastic conduit according to the requirements of ITC-BT-21. A spare conduit with the largest installed diameter is also provided. The calculated voltage drop is maintained below the applicable limit, as verified in the electrical calculations.

Control and Protection Devices

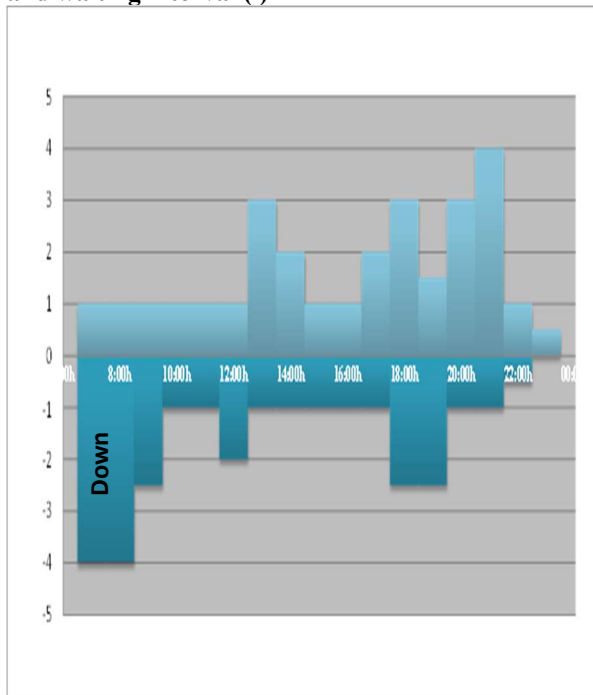
The distribution-board enclosures comply with the specified UNE standards and provide at least **IP30** and **IK07** protection. The enclosure for the power-control switch is sealable and appropriately sized for the selected supply and tariff. Control and protection devices are selected in accordance with the REBT and include suitable protection against **short circuits and**

overloads according to the power and characteristics of each circuit.

6. Traffic Analysis

6.1 Traffic Study

The traffic study evaluates the expected elevator demand in the residential building based on the number of floors, occupants, elevator capacity, operating conditions and passenger movement during different periods of the day. Although traffic studies are commonly applied to high-traffic buildings such as offices, they are also useful here to verify the suitability of the proposed residential elevator. The main parameters considered are **hourly handling capacity (HC), five-minute handling capacity (5C), and waiting interval (i).**



Graph - Relationship between upward and downward traffic and time of day

6.1.1 Theoretical Traffic Study

The proposed elevator has a rated load of **480 kg**, a capacity of **6 persons** and a speed of **1 m/s**, serving four upper floors. The probable number of stops for six passengers is approximately **3.2**. The upward travel distance between probable stops is approximately **3.75 m**, corresponding to about **6.85 s**, while the downward travel distance is approximately **12 m**, requiring about **15.1 s**. For the selected **800 mm side-opening doors**, the door-opening time is approximately **4.3 s**. Including passenger transfer, door operation and a 10% interference allowance, the calculated total stop time is approximately **44.95 s**, with a total travel time

of **37.02 s** and a total cycle time of approximately **81.97 s**.

The probable number of stops can also be calculated using $(S=N-N[(N-1)/N]^P)$, where (N) is the number of upper floors and (P) is the passenger capacity. For **N = 4** and **P = 6**, the calculated value is approximately **3.29 stops**. The theoretical minimum round-trip travel time for a 15 m travel distance at 1 m/s is **30 s**, while the corrected average travel time given in the project calculation is approximately **38.05 s**.

For **incoming traffic**, the elevator mainly transports residents upward from the ground floor. The stop time is calculated from passenger boarding, passenger-transfer and door-operation times using $(t_1=(t_0+t_t+t_p)\text{times}1.1)$. For the six-person elevator, the ground-floor boarding time is **8 s**, passenger-transfer time is approximately $(2N_{PP})$ seconds, and door-operation time depends on the probable number of stops and door dimensions. The complete cycle time is obtained from $(TT=t_1+t_2)$, where (t_2) is the sum of upward and downward travel times.

For **outgoing traffic**, passengers mainly travel downward toward the ground floor. The same cycle-time procedure is applied, but the probable number of downward stops is taken as **75% of the upward stops**, giving approximately **2.4 stops**. The corresponding downward travel distance is approximately **6.25 m**, with a travel time of about **9.35 s** at 1 m/s. Hourly handling capacity is calculated as $(HC=(\text{number of elevators}) \times \text{passengers per journey} \times 3600) / TT)$, while five-minute handling capacity is $(5C=(\text{number of elevators}) \times \text{passengers per journey} \times 300) / TT)$.

Two-way traffic considers simultaneous upward and downward passenger movement. The stopping time includes boarding and exit at the ground floor, passenger-transfer times in both directions and door operation times. The total cycle time is again obtained by adding stopping and travel times. The project calculation identifies a critical traffic condition of approximately **90 s cycle time, 20 passengers in five minutes, and 230–240 passengers per hour**.

The traffic analysis aims to satisfy peak demand, maintain acceptable waiting times and provide convenient access to all residents. The principal design parameters include building use, number of floors, floor-to-floor height, population, floor area, elevator location and passenger demand. Elevator travel time is determined from $(t=X/V)$, where (X) is the travel distance and (V) is the rated speed. The waiting interval is calculated as $(i=TT/\text{number of elevators})$, with the project considering an approximate desirable range of **30–40 s**.

Overall, the theoretical analysis indicates that elevator capacity should be assessed according to the building's actual traffic conditions. Traditional dispatching methods are generally suitable for normal residential applications, while more advanced control algorithms may be required for buildings with complex or high traffic patterns.

6.1.2 Traffic Study Using Sector Software

In addition to the theoretical calculations, elevator traffic can be evaluated using specialised software. The project considers commercial tools associated with **ThyssenKrupp** and **Zener**, with the practical traffic assessment carried out using the online **Zener software tool**. The software-based analysis provides an additional evaluation of passenger handling capacity and waiting-time performance for the proposed elevator installation.

6.2 Results of the Traffic Study Adapted to the Selection of Commercial Equipment Elevator Car

The traffic analysis indicates that an elevator with a capacity of **6 persons** is sufficient to meet the transport

requirements of the two owners' associations. The selected elevator car has a clear internal height of **2.20 m**, with the same height provided at the entrance for normal passenger access. According to **EN 81-1, Article 8.2.3**, the rated load can be determined from the relationship between passenger capacity and rated load, using approximately **80 kg per passenger**. Therefore, for six passengers, the rated load is calculated as $(6 \times 80 = 480)$ kg, giving a rated car load of **480 kg**.

The usable car area is determined from the rated-load requirements of EN 81-1. For a rated load of 450 kg, the referenced table gives a maximum usable area of **1.30 m²**; applying linear interpolation for the selected 480 kg load gives a maximum area of approximately **1.36 m²**. Based on the six-person capacity, the minimum usable car area obtained from the EN 81-1 table is approximately **1.17 m²**. Therefore, the selected elevator car must provide a usable area within the applicable range while accommodating six passengers and a rated load of 480 kg.

Rated load (mass) kg	Maximum useful car area m ²	Rated load (mass) kg	Maximum useful car area m ²
100 ¹⁾	0,37	900	2,20
180 ²⁾	0,58	975	2,35
225	0,70	1 000	2,40
300	0,90	1 050	2,50
375	1,10	1 125	2,65
400	1,17	1 200	2,80
450	1,30	1 250	2,90
525	1,45	1 275	2,95
600	1,60	1 350	3,10
630	1,66	1 425	3,25
675	1,75	1 500	3,40
750	1,90	1 600	3,56
800	2,00	2 000	4,20
825	2,05	2 500 ³⁾	5,00

1) Minimum for a one-person elevator.

2) Minimum for a two-person elevator.

3) For loads above 500 kg, add 0.16 m² per additional 100 kg.

For intermediate loads, the area is determined by linear interpolation.

Table - Maximum and minimum car area

Minimum useful Number of passengers car area m ²		Minimum useful Number of passengers car area m ²	
1	0,28	11	1,87
2	0,49	12	2,01
3	0,60	13	2,15
4	0,79	14	2,29
5	0,98	15	2,43
6	1,17	16	2,57
7	1,31	17	2,71
8	1,45	18	2,85
9	1,59	19	2,99
10	1,73	20	3,13

For more than 20 passengers, add 0.115 m² for each additional passenger.

Table - Passenger capacity in relation to car area (EN 81-1)

7. Conclusions

7.1 Contributions of the Project

The main contribution of this project is the development of an integrated approach to elevator installation in the residential sector. Four key aspects were addressed: the selection of a suitable technical solution for installing an elevator in an existing building; optimisation of construction materials by integrating two buildings through a common staircase and shared easement area; evaluation of eco-efficiency to achieve the highest energy rating, Class A, according to VDI 4707; and application of traffic analysis principles to a residential building for selecting appropriate elevator characteristics.

7.2 Future Research

Future research can focus on four main areas. For the technical solution, self-supporting elevator structures and industrialised construction methods can be investigated to reduce material consumption, installation time and disruption to building occupants. For construction-material optimisation, the existing building stock without elevators can be studied and available construction solutions can be parametrised for different building conditions. In eco-efficiency, further research can examine the storage and reuse of regenerative elevator energy for building services such as lighting, pressure systems, intercoms and telecommunications, while integrating sustainability into both elevator rehabilitation and new construction. The use of renewable energy sources can also be explored to achieve a zero-energy balance. For traffic analysis, national and international elevator markets can be studied according to elevator types and residential usage patterns, with suitable assessment tools incorporated into residential projects. Finally, the developments from these four research areas could be integrated into a single software application to

support the design, evaluation and selection of elevator solutions for residential buildings.

References

- [1]. **AENOR. UNE-EN 81-1:2001. Safety Rules for the Construction and Installation of Lifts. Part 1: Electric Lifts.** Spanish Association for Standardization and Certification, 2001.
- [2]. **AENOR. UNE-EN 81-20:2020. Safety Rules for the Construction and Installation of Lifts. Part 20: Passenger and Goods Passenger Lifts.** Spanish Association for Standardization, 2020.
- [3]. **AENOR. UNE-EN 81-50:2020. Safety Rules for the Construction and Installation of Lifts. Part 50: Design Rules, Calculations, Examinations and Tests of Lift Components.** Spanish Association for Standardization, 2020.
- [4]. **Ascensoristas.net. Technical Forum on Lifts and Lifting Equipment.** n.d.
- [5]. **Ayuntamiento de Salamanca. Municipal Ordinance Regulating the Conditions for Installing Lifts in Existing Residential Buildings.** Official Gazette of the Province of Salamanca, 2010.
- [6]. **Bangash, M. Y. H., and Bangash, T. L. Lifts, Elevators, Escalators and Moving Walkways/Travelators.** Taylor & Francis, 2007.
- [7]. **Barney, Gina C., and Lutfi Al-Sharif. Elevator Traffic Handbook: Theory and Practice.** Routledge/Spon Press, 2003.
- [8]. **Batet Sancliment, D. "Energy Savings in Lifts with VVVF."** *Ascensores y Montacargas*, no. 30, 2002.
- [9]. **CIBSE. Guide D: Transportation Systems in Buildings.** Chartered Institution of Building Services Engineers, 2020.

- [10]. **Technical Building Code (CTE).** Ministry of Transport, Mobility and Urban Agenda, Government of Spain, n.d.
- [11]. **Construmática.** *Hydraulic Lift.* n.d.
- [12]. **Costalift.** *Lift Regulations.* n.d.
- [13]. **Diario de un Ascensorista.** *History of the Lift.* 2013.
- [14]. **Google.** *Google Maps.* n.d.
- [15]. **ISO.** *ISO 25745-2:2015. Energy Performance of Lifts, Escalators and Moving Walks—Part 2: Energy Calculation and Classification for Lifts (Elevators).* International Organization for Standardization, 2015.
- [16]. **ISO.** *ISO 4190-1:2010. Lift (Elevator) Installation—Part 1: Class I, II, III and VI Lifts.* International Organization for Standardization, 2010.
- [17]. **ISO.** *ISO 4190-5:2006. Lift (Elevator) Installation—Part 5: Control Devices, Signals and Additional Fittings.* International Organization for Standardization, 2006.
- [18]. **ISO.** *ISO 8100-1:2026. Lifts for the Transport of Persons and Goods—Part 1: Safety Rules for the Construction and Installation of Passenger and Goods Passenger Lifts.* International Organization for Standardization, 2026.
- [19]. **ITEEA.** *Technological Institute for Lift Study and Training.* n.d.
- [20]. **Janovský, Lubomír.** *Elevator Mechanical Design.* Elevator World, 1999.
- [21]. **Jiménez Moreno, C.** “Energy Savings Applied to Lift Use.” *Técnica Industrial*, no. 234, 1999.
- [22]. **Junta de Castilla y León.** *Law 3/1998, of 24 June, on Accessibility and Removal of Barriers.* Official Gazette of Castile and León, 1998.
- [23]. **Lasheras Esteban, José María.** *Lifts and Escalators.* Cedel, 1980.
- [24]. **Martín Sánchez, Franco.** *New Manual of Electrical Installations.* A. Madrid Vicente Ediciones, 2003.
- [25]. **Ministry of Industry and Energy.** *Royal Decree 2291/1985, of 8 November, Approving the Regulations on Lifting and Handling Equipment.* Official State Gazette, 1985.
- [26]. **Ministry of Industry, Energy and Tourism.** *Royal Decree 88/2013, of 8 February, Approving Supplementary Technical Instruction AEM 1 “Lifts” of the Regulations on Lifting and Handling Equipment.* Official State Gazette, 2013.
- [27]. **Ministry of Industry, Tourism and Trade.** *Technical Application Guide for the Low Voltage Electrotechnical Regulations.* Government of Spain, n.d.
- [28]. **Ministry of Industry, Tourism and Trade.** *Royal Decree 842/2002, of 2 August, Approving the Low Voltage Electrotechnical Regulations.* Official State Gazette, 2002.
- [29]. **Ministry of Industry, Tourism and Trade.** *Royal Decree 1890/2008, of 14 November, Approving the Energy Efficiency Regulations for Outdoor Lighting Installations and Supplementary Technical Instructions EA-01 to EA-07.* Official State Gazette, 2008.
- [30]. **Miravete de Marco, Antonio, and Emilio Larrodé Pellicer.** *Lifts: Principles and Innovations.* Reverté, 2007.
- [31]. **Miravete de Marco, Antonio, and Emilio Larrodé Pellicer.** *The Book of Vertical Transport.* Ed. Miravete/Centro Politécnico Superior, University of Zaragoza, 1996.
- [32]. **European Parliament and Council of the European Union.** *Directive 95/16/EC on the Approximation of the Laws of the Member States Relating to Lifts.* Official Journal of the European Communities, 1995.
- [33]. **Patentados.com.** *Hydraulic Lift with a Pressure Accumulator and Related Procedures.* n.d.
- [34]. **Peters, Richard D.** “Lift Traffic Analysis: Formulae for the General Case.” *Building Services Engineering Research and Technology*, vol. 11, no. 2, 1990.
- [35]. **Peters, Richard D., and P. Mehta.** “Green Lift Control Strategies.” *International Journal of Elevator Engineers*, vol. 2, 1998.
- [36]. **Peters, Richard D., P. Mehta, and J. Haddon.** “Lift Traffic Analysis: General Formulae for Double Deck Lifts.” *Building Services Engineering Research and Technology*, vol. 17, no. 4, 1996.
- [37]. **Community of Madrid.** *Lift Renewal Plan.* n.d.
- [38]. **Revista del Ascensor.** *Revista del Ascensor.* n.d.
- [39]. **Strakosch, George R., and Robert S. Caporale, eds.** *The Vertical Transportation Handbook.* John Wiley & Sons/Elevator World, 2010.



- [40]. **Universidad Carlos III de Madrid.** *Transport Engineering Lecture Notes.* n.d.
- [41]. **Universidad de Salamanca.** *Lecture Notes on Lifting and Transport Systems.* n.d.
- [42]. **Universidad de Salamanca.** *Project and Resource Library of the Mechanical Engineering Area.* n.d.
- [43]. **Universitat Politècnica de Catalunya.** *UPCommons: Institutional Repository of Projects and Academic Works.* n.d.
- [44]. **VDI.** *VDI 4707 Blatt 1. Aufzüge—Energieeffizienz / Lifts—Energy Efficiency.* Verein Deutscher Ingenieure, 2009.