white paper

FROM SMART LOCKS TO WISE LOCKS

new models of building spaces management for energy savings

Working Group

Module 1: T. Poli, A. G. Mainini, M. S. Majour, E. Casolari, A. Speroni, M. Cavaglià, J.D. Blanco cadena (SEEDLAB.ABC, ABC dept., Politecnico di Milano)

Module 2: F. Pittau, A. Speroni, R. Riva, G. Amendola

Prof. Tiziana Poli, Andrea Giovanni Mainini, Francesco Pittau

Department of Architecture, Built Environment and Construction Engineering of **Politecnico di Milano**

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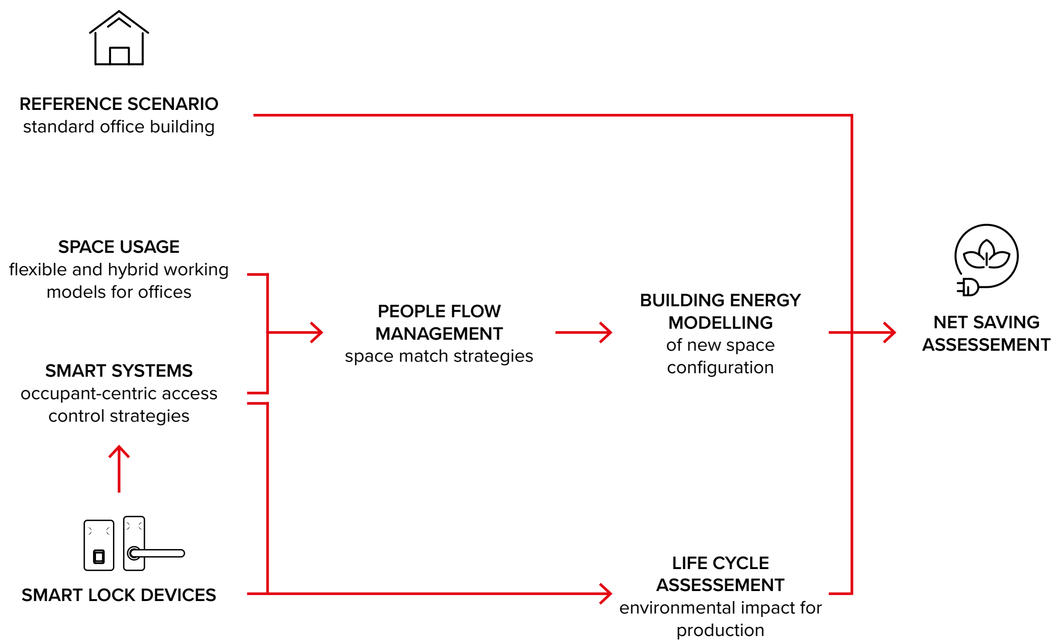
SHORT ABSTRACT

This comprehensive white paper explores the concept of "Wise Locking" as an alternative approach to conventional smart locking systems. Emphasizing energy savings and operational resource optimization, the paper delves into the application of wise locking systems for enhancing building utilization through partialization, schedule optimization, and on-demand occupancy management in alignment with the dynamic landscape of smart working. Providing not only a theoretical foundation but also practical insights, case studies, and detailed recommendations, this document proposes the adoption of wise locking systems as an intelligent strategy for reducing energy consumption, optimizing resource utilization, and improving overall building management in diverse environments, such as a contribute to positive living. An LCA analysis carried out both for the comparison of the two devices, mechanical vs. electronic, and for the expected impact for the production and installation of the system, also shows how the initial environmental impact can be effectively offset over the service life of the system by the savings achieved through an optimised building management system.

GRAPHICAL ABSTRACT



SCOPE OF THE WORK

The goal of this work is to investigate, through a life cycle approach, how the use of wise locking systems for access management may provide a valid contribution to energy and carbon saving when applied to a building for enhancing utilization.

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KEY FACTS

1. A comprehensive operational plan that incorporates smart locks could promote a lean building automation framework exploiting the capabilities of the building manager in addressing and redirecting people inside the building by a specific operational need.
2. The concept of buffer spaces in the management model for energy savings involves designating areas for redirected occupants during varying building use or flexible work arrangements, contributing to the optimization of energy efficiency.
3. In the analyzed case study, optimizing daily half-floor closures led to a closed building percentage ranging from 11.6% to 13.2% (a 10% decrease in building occupancy). This approach also brought about a significant reduction in standardized annual costs (12.9% to 14.3%) and a decrease in primary energy consumption (56 MWh to 123 MWh), depending on the chosen ISO standard (ISO 17772-2 or ISO 18523-1).
4. The production of electronic devices for building access management is affected by imported processes for electronic components that increase by more than double the environmental impacts, compared to conventional mechanical systems.
5. Even though the initial carbon spike of the "smart" system when applied to the case study, the initial impact as well as the one provided by replacement and maintenance of the infrastructure is immediately compensated by the energy saving from building operation, which reduces the carbon emissions by 940 tons by 20 years of service life.

1. INTRODUCTION

Global energy demand is increasing, such as the related environmental concerns. Energy efficiency and related energy savings from the use of innovative solutions, such as high-performance insulation, novel envelope materials, and HVAC systems, have demonstrated their limitation in achieving absolute sustainability due to the high carbon spike given by the embodied emissions for material processing. Energy sufficiency, contrarily, provides a practical contribution to the rapid decarbonization of buildings as a more conscious use of the space through an aided management of the operative energy for the usage of the indoor environment may immediately cut the energy demand without affecting the comfort of the users. Within the building sector, particularly in the context of retrofitting projects, there exists a prevalent practice known as deep retrofitting. Typically, this process involves extensive modifications to the building envelope and the replacement of building services and systems, which require large investments and discomfort for the users. Moreover, the carbon spike provided by new material installation can dominate the life cycle of the building over the remaining service years, with a serious risk of lock-in effect. On the other hand, innovative operative energy management concepts, such as load shifting, peak shaving, and demand response services, bolstered by the integration of cutting-edge technologies like IoT devices, machine learning algorithms, and cloud-based platforms, can provide a valid contribution to achieving energy sufficiency in buildings. These insights not only pave the way for the evolution of comprehensive energy management systems but also set the stage for a transformative paradigm in a novel approach to energy utilization. However, within this realm, there is a notable gap that leaves room for softer, leaner interventions. These interventions, characterized by minimal but strategic adjustments, hold the potential for significant energy savings without investing in initial carbon spikes and users' discomfort. This work explores the gaps between hard and soft retrofitting, shedding light on how modest yet targeted interventions can yield substantial gains in energy saving, especially in building retrofit. Building automation offers context to the evolution of intelligent systems emphasizing their transformative potential and promoting systems and technologies that can optimize energy usage, with specific attention to lighting and thermal management.

1.1. From Smart Locks to Wise Locks in Building Automation

Smart locks are advanced locking mechanisms designed to provide secure access control through electronic and connectivity features. Unlike traditional locks, smart locks leverage communication technologies to enable keyless entry, remote monitoring, and programmable access permissions. These locks often integrate with mobile applications or central building automation systems. The integration of smart locks, especially into office building systems could lead to an improvement in building operational efficiency and management by merging access control systems and operational protocols. A comprehensive operational plan that incorporates smart locks could promote a lean building automation framework exploiting the capabilities of the building manager in addressing and redirecting people inside the building by a specific operational need. Among the possible operational scenarios smart locks, here renamed “Wise locks”, introduce a new dimension to energy efficiency by enabling precise access control for partial building closures. A selective restriction of access to specific areas could optimize energy usage by confining occupancy, in real-time, to other building areas (Figure 1) and designated zones (buffer spaces) during non-peak hours or reduced activity periods. A direct connection with Building management systems could then include adjusting lighting, HVAC systems, and appliance consumption under variations in building occupancy and promoting an efficiency gain.

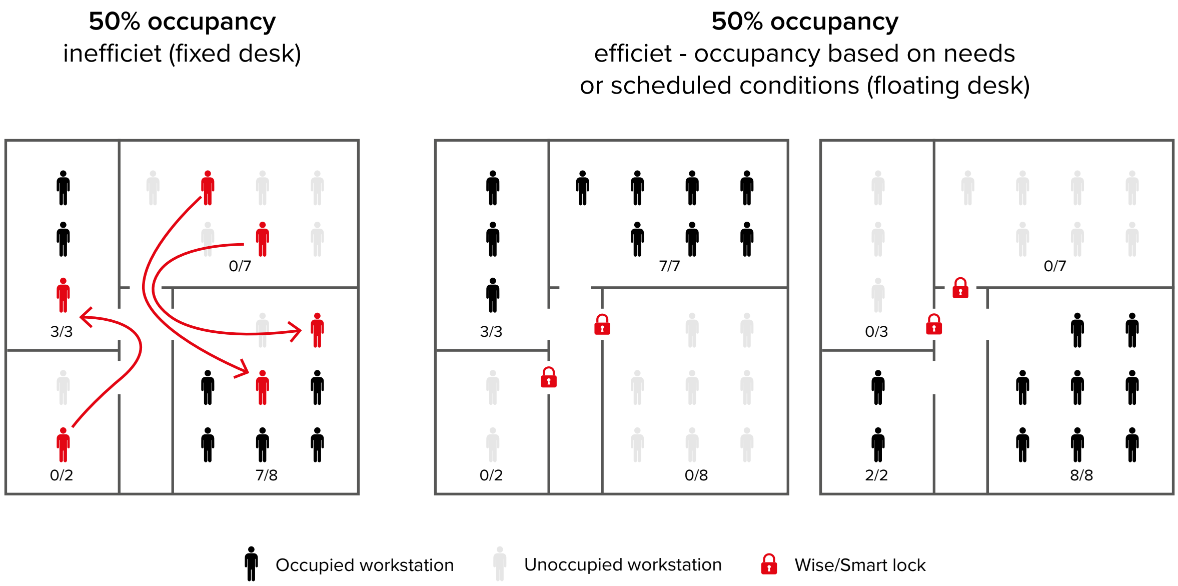


Figure 1: Occupancy management through wise locking capabilities (© SEEDLAB, ABC dept.)

1.2. Adaptive Work Models and buffer spaces

The shift towards adaptive and smart working models involves embracing remote work and flexible schedules, as well as efficiently managing in-office occupancy. Realistic occupancy schedules are pivotal in optimizing energy utilization within the workplace. In fact, by connecting real-time assessment, forecasting, or scheduled in-office presence with operational requirements the organizations can minimize unnecessary energy consumption during periods of low occupancy, helping building managers to meet energysaving goals. It is assumed that the building must be able to guarantee partial operation, i.e. that installed systems and facilities can modulate or locally interrupt their operation concerning space management. The first step in establishing the layout for smart locks involves examining the functions of building spaces and the type of occupancy they serve. These two parameters are essential for determining the adaptability of building spaces. As a second step, the analysis of door hierarchy is provided for the selected floors and spaces (Figure 2). This method entails assigning sequential door numbers based on the number of doors needed to access a designated area. The examination of door hierarchy serves to elucidate the flow of people within the building, contributing to the development of an optimized final smart/wise lock layout.

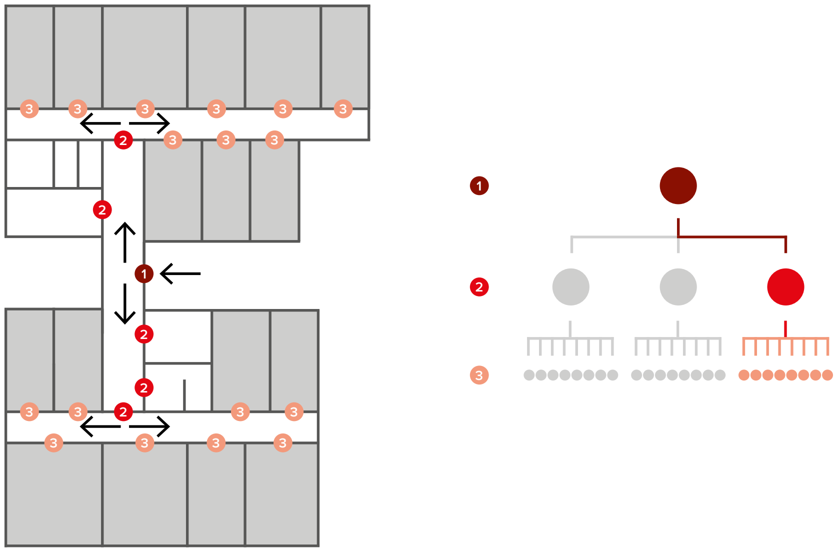


Figure 2: Door hierarchy assessment and test case building floor plan.
The north is on top. The building structure has two wings with a distribution corridor in between (© SEEDLAB, ABC dept.)

In the pursuit of a new management model designed for energy savings, the concept of buffer spaces emerges as a strategic component. Buffer spaces are areas designated for redirected occupants during times of varying building use or in response to flexible work arrangements (Figure 3).

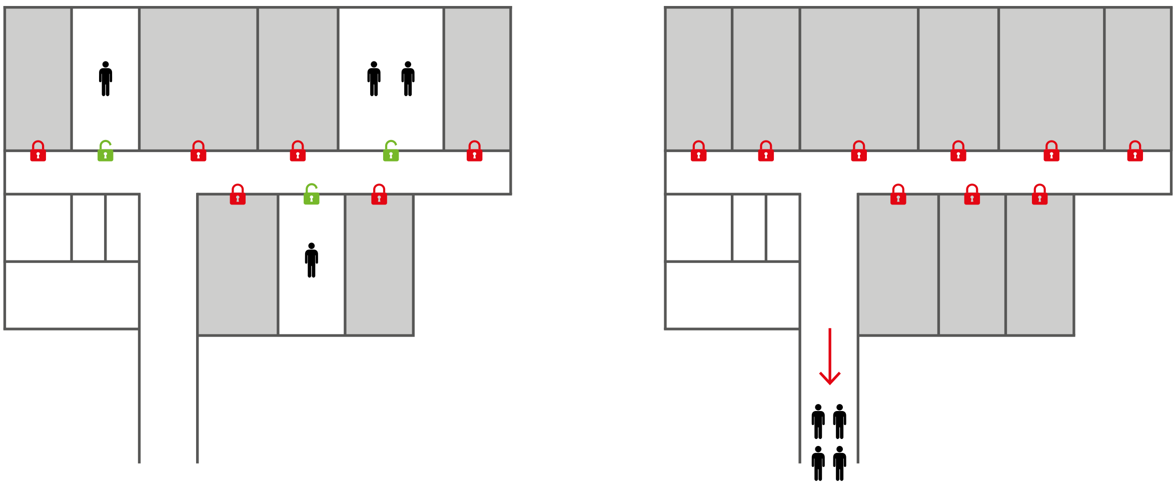


Figure 3: The usage of buffer spaces (© SEEDLAB, ABC dept.)

These spaces can serve as versatile environments, seamlessly transitioning between collaborative and individual work settings. Spaces with greater flexibility can accommodate additional occupancy and facilitate the redistribution of individuals when other areas are closed. Consequently, such flexible spaces make ideal candidates for conversion into buffer spaces.

Among the possible operating strategy, the building manager can:

- Consider that in the event of low occupancy of one or more parts of the building, the users can be grouped into a dedicated space, defined for the purpose.
- Close a portion of the building, if this is the most energy-intensive and subject to discomfort conditions at a given time of year.

2. A CASE STUDY ASSESSMENT

2.1. Evaluation of energy savings achieved through the implementation of space management strategies

In the absence of a dedicated case study, but to evaluate potential impacts arising from the implementation of the access management system, Building 15 at Politecnico di Milano, Campus Bonardi, has been selected as a virtual case study. The building is composed of two volumes connected through a central corridor; its H-shaped floor plan symmetry and the clear north-south orientation of the volumes provide an ideal setting for applying space optimization strategies (Figure 2 and 3). The building comprises a predominantly technical basement, two above-ground floors in the north wing, and three above-ground floors in the south wing.

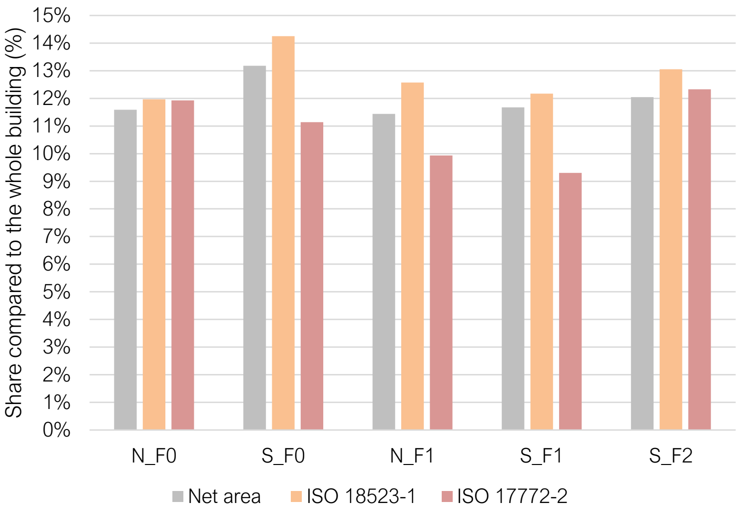
Module 1 focuses on the assessment of the potential savings resulting from the optimization of space utilization through the use of ISEO smart locks. The analysis is structured in a preliminary phase (1) to define effective occupancy management and closure strategies, followed by a second phase (2) for the dynamic energy modeling of the building. This involves comparing energy consumption with and without occupancy optimization.

During the preliminary phase (1), data on the building construction are obtained from the energy certification conducted in 2007. The building has poor thermal insulation, features double-glazed windows, and does not have manual or automatic solar shading systems. Additionally, there are no lighting control systems in place, as the lighting follows the occupancy profile. The analysis, not falling within the scope of post-occupancy evaluation with assessments of real consumption and use, was considered according to two standardized use states, adhering to reference regulations. ISO 17772-2 and ISO 18523-1 standards guided the consideration of occupancy hours, lighting levels, and other equipment. Both standards were taken into account, particularly concerning occupancy hours and lighting levels, to provide a sufficiently broad range of potential savings for the actual building. The estimation of primary energy needs and operating costs for the heating/cooling system was obtained using a simplified methodology. This methodology considers both useful energy needs and reference values for the efficiency of the heating system (eta=0.95) and cooling system (COP=2.5), along with an ideal ventilation contribution to ensure compliance with regulations.

Once the building construction and systems were defined, the functions and occupancy types for each space were examined. The goal was to identify suitable areas for relocating workstations, while also establishing a hierarchical model for space access and utilization.

This analysis facilitated the grouping of spaces based on shared accesses. As a result, five potential partial closures of the building were identified, corresponding to the five aboveground levels. This choice did not account for daily usage preferences and needs, which were not available at the time of the analysis. Instead, it considered the technical feasibility of installation and maximum theoretical savings.

The partial closures aligned with the need to exclude spaces with the highest daily consumption relative to the reference climate. Buffer spaces on each floor allowed for redirecting people flows according to (a) a voluntary smart working occupancy model in real-time or (b) one scheduled by the building manager. Thus, the results obtained through energy analysis should be considered indicative and not directly reflective of a specific real-world scenario. During the second phase (2), the building was modeled through dynamic simulation, implementing the partial closures of the levels according to the hierarchical model identified in the preliminary phase. The building loads in various configurations were assessed and reported in terms of primary energy, costs, and carbon emissions. Primary energy conversion factors were sourced from the ENEA report implementing the EPBD 2020, costs were calculated considering fixed and variable gas and electricity prices in the 2021-2023 period provided by ARERA, and emission factors were supplied by the annex H to the decree 18456 of Lombardy Region. As a synthetic result, it was calculated that it is possible to reduce standardized annual costs between 12.9% (ISO 17772-2) and 14.3% (ISO 18523-1) and primary energy by 56 MWh (ISO 17772-2) and 123 MWh (ISO 18523-1) (estimates relative to the standardized case study with simplified building systems) by optimally closing one half-floor per day, equivalent to a 10% reduction in the number of people in the building and with a closed building percentage ranging from 11.6% to 13.2%. (Figure 4)



N_FO	North Wing Ground Floor
S_FO	South Wing Ground Floor
N_F1	North Wing First Floor
S_F1	South Wing First Floor
S_F2	South Wing Second Floor

Figure 4: Primary energy savings under the hypothesis of the annual closure of an entire half-floor (© SEEDLAB, ABC dept.)

This reduction in primary energy translates to an annual building emissions reduction of 21.30 tonCO2eq out of the initial building's 159.60 tonCO2eq (ISO 17772-2) and 49.78 tonCO2eq out of the initial building's 344.52 tonCO2eq (ISO 18523-1) (estimate with standardized emission coefficients).

Considering the estimate of daily savings, these range from 0.03 to 0.3 euros per square meter of closed heated/cooled space, depending on the standardized consumption scenario of the building. The partial closure strategy can be studied for days or periods of particular energy intensity, but it must be assessed locally for each building, estimating derived savings cycles and profiles while also considering the variability of energy costs.

Considering this approach and evaluating the closure of only the floors that optimize the reduction in energy consumption, it is possible to define an ideal process called "Best Closure Fit" which optimizes the average daily savings depending on the day and time of the year. This process is presented as an example concerning the ideal case study but could be implemented with a predictive logic for space management.

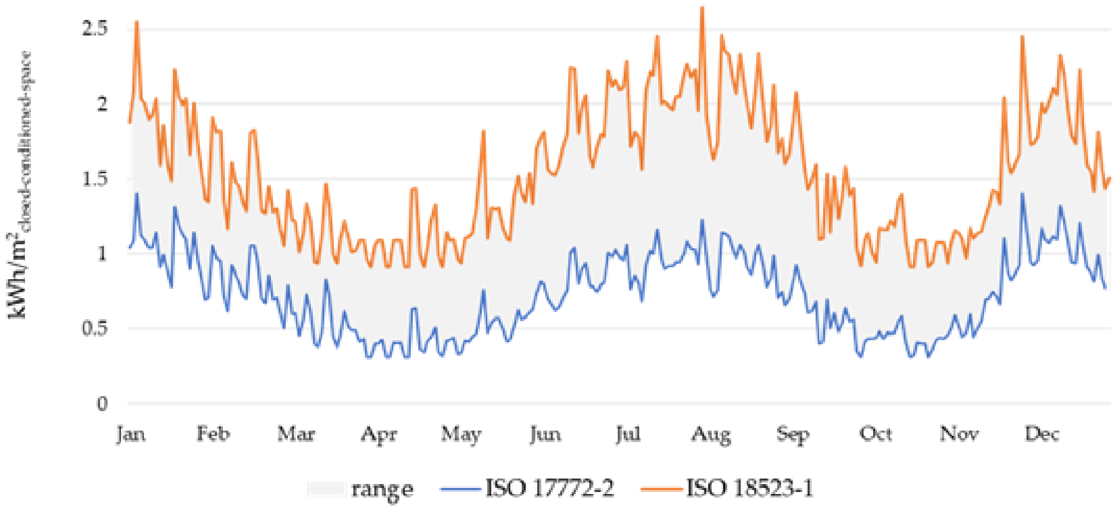


Figure 5 an example of the best closure fit approach, on a daily basis. The gray area represents possible intermediate savings, considering the two standardized profiles as a reference. (© SEEDLAB, ABC dept.)

Additionally, the occupancy levels of a typical open-space area were assessed based on its real-world usage. The monitoring activity included a direct headcount of individuals through voluntary completion of an access form, along with an evaluation of the opening and closing cycles of entrances using sensors installed on door frames and communication gateways located in the corridors. The measured occupancy profiles reflect the trends outlined by the standard regulations used for the assessment. However, it is not feasible to reconstruct the number of individuals within a shared space solely by monitoring and assessing the patterns of door opening and closing cycles.

2.2. Life cycle environmental impact analysis

The Life Cycle Assessment (LCA) was structured to estimate the environmental impacts and primary energy requirements from the production and management of ISEO access control systems. In particular, the work was set up according to two distinct phases: 3.1. Comparative evaluation of the mechanical device (conventional) vs. Libra electronic device (smart); 3.2. Evaluation of the gate control system, according to the architecture designed in the case study under examination, Building 15 of Politecnico di Milano, Bonardi Campus, and comparison of the results with the conventional mechanical system.

The methodology applied to the two study phases was based on the ISO 14040 standard. This was structured according to the following sub-phases: (I) definition of the scope of the analysis; (II) choice of the functional unit; (III) selection of the environmental impact categories; (IV) primary data collection and definition of allocation methods; (V) development of the input-output matrix; (VI) selection of the LCA dataset for the assessment models; (VII) choice of the assessment method to be applied to the LCI; (VIII) comparison and interpretation of the results.

2.2.1.Comparative LCA for production: mechanical device vs. electronic device

For the comparison of the two alternative devices for the access control, the analysis was carried out "from cradle to gate" (module A1-3), identifying the production gate as the "gate", while the functional unit (FU) was considered to be 1 finished and packaged device, ready to be placed on the market.

Through the direct collection of primary data, which took place at the Pisogne production site, the main material and energy flows characterising ISEO production were reconstructed, as well as the generation of waste and the movement of goods and transport, for both the analysed devices. From the collection phase, an input-output matrix was generated based on mass allocation principles, which was modelled with the software SimaPro 9.5 and the processes linked to ecoinvent 3.9 database.

Then, the inventory generated in the LCI phase was processed in the assessment phase according to the EPD method, based on the analysis of 7 environmental impact categories shown in Figure 6 and Figure 7: 1) Acidification; 2) Eutrophication; 3) Global Warming Potential (GWP100a); 4) Photochemical Oxidation; 5) Abiotic Depletion; 6) Water Scarcity); 7) Ozone Depletion.

The analysis of the results shows how the environmental impacts generated by the production of the mechanical device, in particular the GWP100a, are strongly influenced by the production of brass (almost 70%), which within the contribution of packaging (about 15%) result as the two most influential processes, about 5/6 of the whole production. Following, the main contribution is made by the production of the shaped body, followed by cylinder production, packaging, key shaping, cylinder spacer production, and so on.

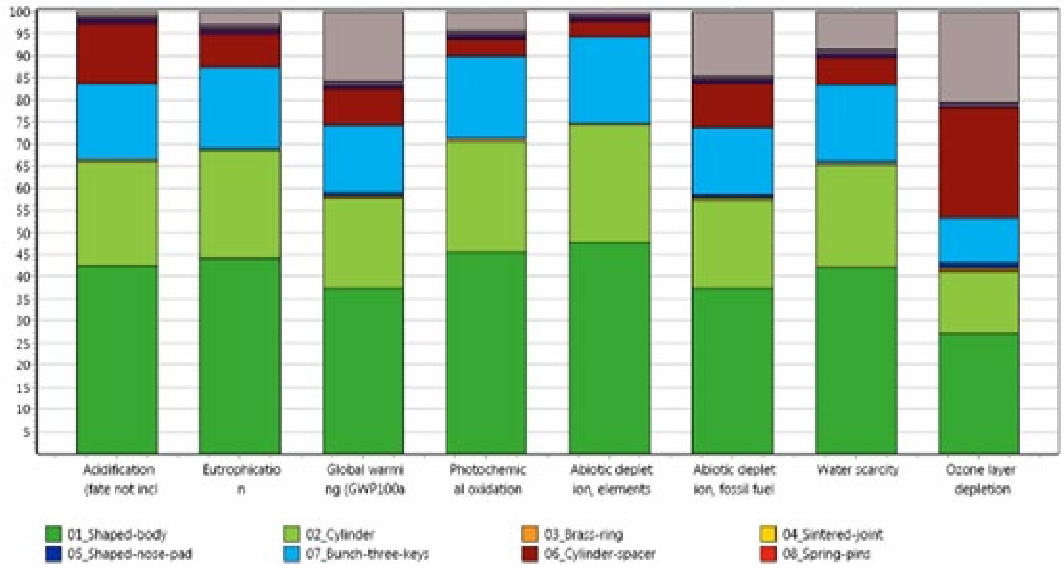


Figure 6: The seven impact categories selected for the comparative LCA of the mechanical device and the relative influence of the working activities. (© DABC)

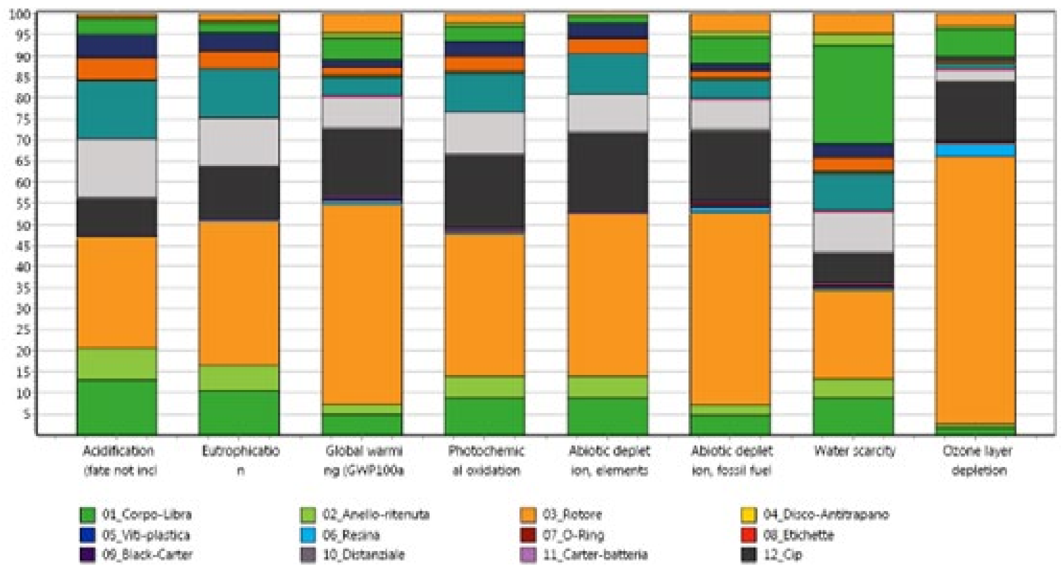


Figure 7: The seven impact categories selected for the comparative LCA of the electronic device and the relative influence of the working activities. (© DABC)

The production of the LIBRA device generally sees an increase in environmental impacts, most of which are 'imported' through the use of pre-assembled components. In particular, the GWP100a indicator sees an increase of the emissions more than double the one of the mechanical device, 5.7 kgCO2-eq/FU vs. 2.3 kgCO2-eq/FU. Here, the main contribution is given by the rotor, which accounts for almost 50% of the total impact, and the electronic cards, which provide an additional 16% contribution. The most relevant stages are the rotor production (imported impact), followed by the production of the chip (imported impact), the cylinder body, the extension, the libra body, the packaging, and then all the others.

2.2.2.Carbon emissions from the production and installation of the system applied i n the case study

For the analysis of the system, when applied to the case study under examination, in addition to module A1-3 (production), the phases B1 (use), B2 (maintenance) and B4 (replacement) were also included, calculated over a time horizon of 20 years. For the 'smart system' architecture, two design configurations were developed: 1) a Libra device for each access; 2) optimisation of the number of devices, placed only at the seven accesses that split the building wings. As shown in (Figure 8), the use of a 'smart system', based on the non-optimised architecture, entails an environmental commitment, in terms of emissions, of almost 3.5 tonnes of CO2-eq over 20 years of use, compared to the 160 kilograms measured for the conventional mechanical system (reference).

If the number of installed devices is optimised, the emissions drop by approximately 42% to just over 2 tonnes of CO2-eq over the same time horizon considered for the analysis.

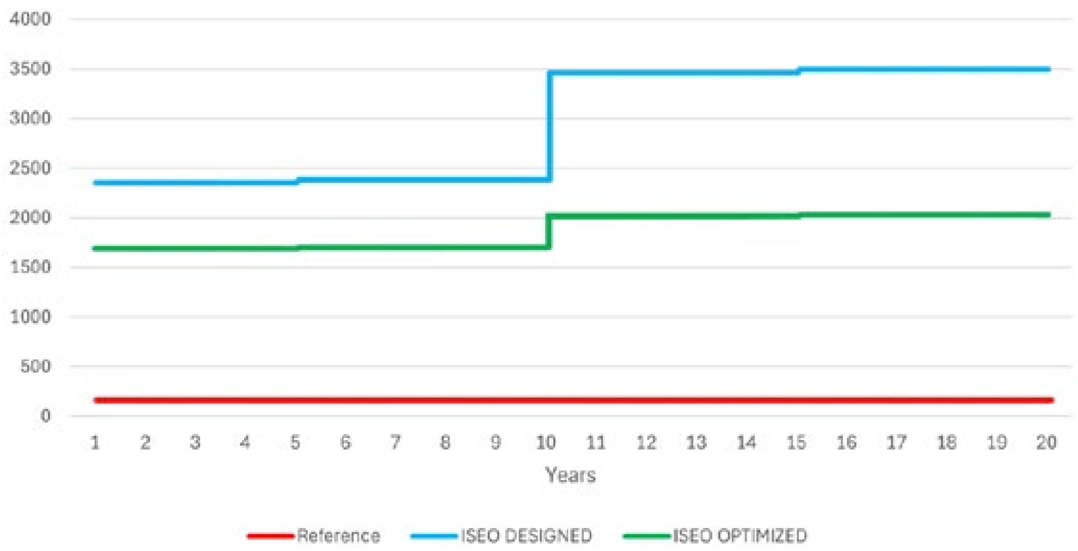


Figure 8: Carbon emission of the three compared systems applied on the case study over a time horizon of 20 years. (© DABC)

2.3. Carbon footprint assessment and CO2 savings from wise lock management system

These numbers, when merged with the avoided operational energy consumption - and thus avoided CO2-eq - for space heating and cooling, show how, in a 20-year life cycle scenario, it is possible to reduce emissions by up to 940 tonnes of CO2-eq, depending on the occupancy profile considered.

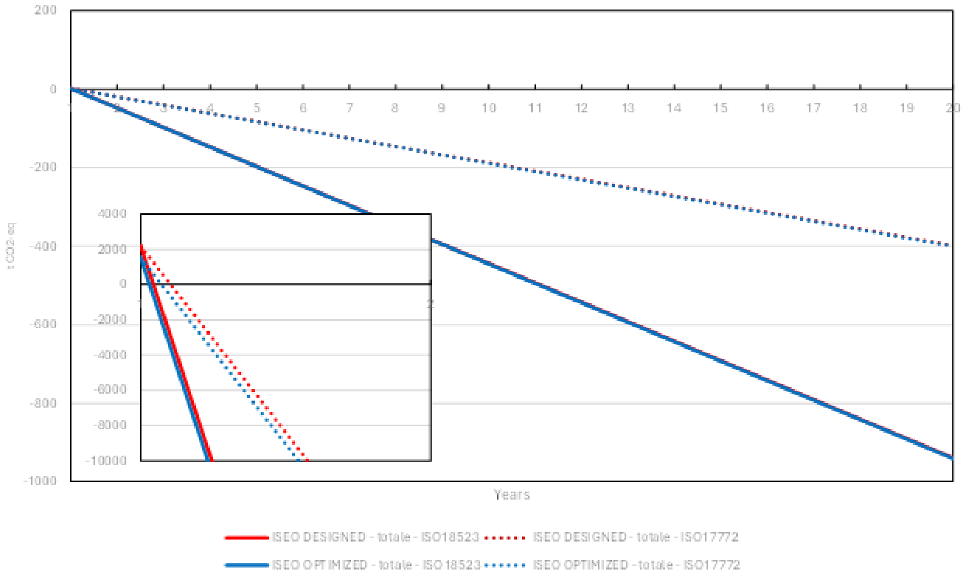


Figure 9: Life cycle carbon savings (embodied + operational) measured from wise-looking management when applied to the case study over a time horizon of 20 years. (© DABC)

The results show how (Figure 9), in a life-cycle scenario, an increased emission from the production of the devices and the management of the system can be completely offset by the emissions avoided in the use phase due to the space optimization provided by the smart access control system that favours the partial use of spaces. In conclusion, the achieved results place the system in a solid position among the viable efficient solutions for energy savings in buildings.

3. CONCLUSIONS

The research investigated the concept of the holistic vision of creating wise buildings through the transformation of locking systems. It encapsulates the key elements of partialization, schedule optimization, and on-demand occupancy management within the comprehensive framework of wise locking systems.

The conducted study assessed the feasibility of reducing consumption by implementing a partial use of the building. Under the limitation of the specific model considered and under the proposed standardized usage hypothesis, a direct proportionality between the area subject to closure and the achievable economic and energy savings becomes apparent. Furthermore, through the comparison of results based on the two standards, it is evident that different patterns of usage and occupancy significantly impact energy savings, highlighting the need to develop a closure strategy in relation to actual occupancy.

In conclusion, the production of electronic devices for building access management carries a larger environmental impact than conventional locking systems due to imported processes for electronic components. Despite an initial carbon spike, the energy savings achieved during building operation, through his reference service life, more than compensate the environmental footprint spent for the production and system installation and management.

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4. RECOMMENDATIONS

1. Embrace the concept of door hierarchy to guide the organization of building spaces, ensuring that closures align seamlessly with these designated groups.
2. Select or design buffer spaces based on their energy efficiency attributes, and size them according to the desired level of adaptability.
3. Occupancy profiles are uncertain, but decisive for the building's energy efficiency: employ strategic space management techniques to anticipate and influence the flow of people within the building.
4. Leverage or exploit building exposure features: i.e. group people in the South exposed zones in winter, while North exposed in summer or, in general, assess the residual comfort capabilities (i.e. free floating temperature ranges)
5. Identify spaces that are overly exposed or insufficiently insulated, as these may be prime candidates for closure.
6. Tailor closure plans to the weight classification of the building. For medium or heavy-weight structures, establish closures weekly, while for light-weight buildings, daily closure definitions may be more appropriate.
7. Consider updated energy prices and assess promptly the energy demand through post-occupancy evaluations.
8. Integrate predictive data analysis processes (BIM models and virtual sensors), or ensure compatibility with building management systems.
9. Address promptly potential challenges in implementing partial closures and adaptive work models, such as security issues related to flexible access.
10. Address properly the complexity in system integration, data availability, data privacy and the lack of standardized methodologies.

5. LIMITATIONS OF THE STUDY

1. The simplification of the building operating model is allowed to the extent that the real usage profile of the building is unknown. The occupancy standard has been ensured in compliance with the profiles specified by regulations for all the same types of typical environments. No sun-shading or internal lighting control and management systems are provided. The variability of electrical consumption and related primary energy consumption could therefore be significantly influenced.
2. The estimation of primary energy consumption and operating costs has been carried out using simplified calculation methodologies based on standard coefficients of utilization and efficiency.
3. The prices of energy vectors have been considered for the period 2021-2023, during which there was a peak increase in energy costs. Different reference periods or current energy costs could lead to different results.
4. The model envisions the partial closure of a half floor and the simultaneous deactivation of systems, i.e., the partialization of services. In a real-world scenario, this kind of approach must be feasible and manageable through building managers or Building Management Systems (BMS). Future reduced carbon emission factor of the national energy-mix was not considered in the carbon footprint analysis of the products' life cycle, which may lead to significant saving reduction in case of fast decarbonation of the energy grid.
5. Due to lack of data, all imported processed in the Life cycle analysis for the production of the electronic devices were assumed from ecoinvent database as general process (either regional or global), which may not be necessarily representative of the specific case under analysis.

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ISEO Serrature s.p.a.
Via San Girolamo, 13
25055 Pisogne BS, Italy
Tel. +39 0364 8821
iseo@iseo.com

iseo.com