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***Abstract*——— This work aims to propose a case study for the calculation of the energy performance of lighting systems in a retirement home. The proposed methodology evaluates the energy consumption of lighting systems in the presence of daytime lighting and occupancy control strategies with the Lighting Energy Numerical Indicator (LENI). The effect of natural light, the LED sources, the external obstructions, as well as building orientation and shading systems, can influence the energy consumption of the lighting systems. The case study analysed was the "Brancaccio retirement home" located in Matera (Southern part of Italy). The results of this work refer to both annual and monthly energy consumptions, and underline how important it is to evaluate the amount of energy throughout the year in the presence of control systems, given the considerable monthly variation. Furthermore, the LED source is able to significantly reduce energy consumption compared to fluorescent lamps, and this energy saving can be further increased in the presence of control systems.**

Keywords— LENI, EN 15193, energy consumption, artificial lighting, control strategies

I. INTRODUCTION

EN 15193-1 [1],[2] standard, providing numerical indicator for efficiency of lighting systems (LENI, lighting Energy Numeric Indicator), may give a decisive contribution to energy-conscious lighting design.

The correlations between maintaining optimal lighting comfort conditions and saving electricity through the use of automated control systems, which integrate natural light with artificial light (smart lighting), in the presence of users, are now well known and widely recognized.

The standard allows the evaluation of the LENI even in the presence of control systems that can increase the complexity of the management profiles of the system and consequently the quantification of the estimate of energy needs for lighting.

The importance of the evaluation of the LENI is fundamental to determine the effectiveness of a lighting control system in order to calculate the energy savings introduced by it compared to a non-automated solution.

In this work, the application of LENI is presented for an interesting case study, i.e., a building used as a permanent retirement home for the elderly.

The complexity of the case study is due to the functional coexistence, within the same building, of services related to the home (private living), the care function (hospital), and offices. This type of building, where services and comfort are required 24 hours a day, 365 days a year, outlines a particularly complex energy management profile.

The requirements of comfort and visual performance of care and health facilities are regulated by EN 12464-1 [3].

It is estimated that, in facilities such as hospitals, clinics and nursing homes, lighting is responsible for up to 40% of total energy consumption. In these situations, artificial lighting is necessary to guarantee inpatients conditions of visual comfort, in situations of extreme fragility. The lighting design must be particularly accurate in ensuring the necessary comfort conditions and, at the same time, in containing energy consumption.

In this study, the LENICALC software [4] was used to calculate the annual energy requirement for artificial lighting. This software, developed by ENEA, provides the output information according to EN 15193-1 standard [1].

LENICALC objective is to support professionals and designers in overcoming the complexities of multidisciplinary procedures imposed by the standard evaluation and certification of lighting systems.

In this context, the study presented achieves the following goals:

- apply the "comprehensive" standard procedure for calculating the LENI, in a real case study with a specific intended use,
- analyse the influence of different factors on the energy needs for artificial lighting and compare the results obtained on the basis of changes in the LENI index and monthly specific energy,
- explore the potential and limits of the LENICALC software and the possible "grey areas" of the standard.

The description of the calculation methodology and how to use the software are explained in section 1, the case study is presented in section 2 and the results are discussed in section 3.

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The analysis carried out in this work starts from previous studies concerning the influence of lighting on the energy performance of buildings, through the evaluation of internal heat inputs related to the artificial lighting system, both for office buildings [5] and for buildings used as retirement homes [6], [7].

II. Standards, LENI and Software

The European standard EN 15193-1 [1] establishes the methodology for evaluating the energy performance of lighting systems, both for new, existing or retrofitted buildings. It provides a calculation methodology based on the LENI, intended as the annual energy consumption for artificial lighting per surface area of the building.

The calculation of energy consumption is determined by considering the reduction in consumption in relation both to the availability of natural light, entering the indoor environment, and to the potential of the control logic that exploits the amount of light available (photo sensor) which will in fact reduce the amount of artificial light needed to ensure the visual performance requirements. In the calculation procedure, the standard actually considers the daylight factor determined in the area A_D of the room (i.e., area with daylight contribution), in the presence of openings (e.g., vertical and sloped windows or rooflights). Given a daylight factor, the calculation takes into account purely geometric parameters to determine the potential natural light inside the room, in relation to window-to-wall ratio, obstructions and characteristics of transparent components.

In addition, in order to consider the possible presence of shading devices for direct solar radiation, the luminous exposure is considered, which takes into account the spatial and temporal distribution of external light. Also in this case, however, daylight factor takes into account the amount of natural light in the presence or the absence of shading devices that correlates the values of the luminous exposure, obtained from the ratio Hdir / Hglob, (luminous exposure from direct / global insolation), for different climate conditions, orientations of the façade, latitudes and maintained illuminances E_m required. This further calculation, summarized in tables, is a simplified attempt to consider in the calculation also the component of direct solar radiation that would be shielded with shading devices [2],[8].

A. The Lighting Energy Numeric Indicator (LENI)

The evaluation of the LENI index can be carried out, for existing or new buildings, according to three different methodologies (Fig. 1): two of which are calculated (i.e., Methods 1 and 2) and one measured (i.e., Method 3).

The parameters to be considered take into account: type of use and management of artificial lighting systems, availability of daylight inside the rooms, consumption due to lighting for emergency and control systems.

The standard, and consequently the LENI, assumes that the design of the lighting system complies with the comfort requirements in the lighting applications standards, e.g., EN 12464-1 [3] for indoor workplaces.

The LENI index is defined as follows:

$$\text{LENI} = W/A, \ \text{kWh/m}^2\text{/year} \quad (1)$$

i.e., the energy required for lighting W [kWh/year] is divided by the net useful area [A] of the building; W is the sum of two contributions: W_L (total annual energy for lighting), representing the energy consumption necessary for the lighting system to ensure comfortable lighting conditions set in the design stage and W_P (total annual parasitic energy), representing the energy requirement necessary to power the emergency devices and to maintain the stand-by conditions of the control systems of artificial lighting.

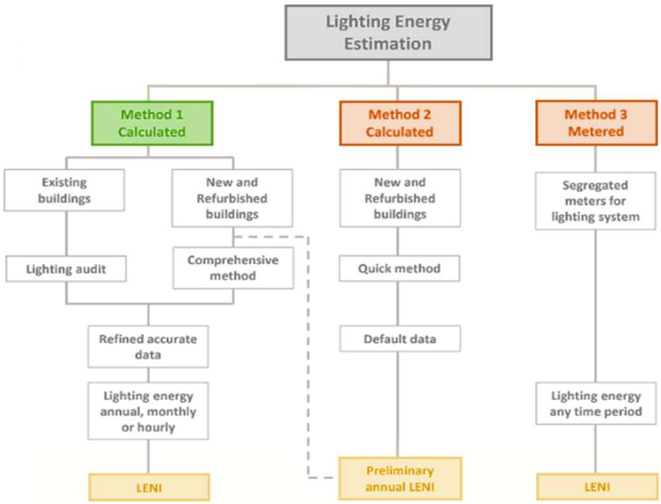

Fig. 1. Methods for evaluating LENI

Many factors influence the calculation of W_L and W_P such as: installed powers (P_n), parasitic powers of the control devices (P_{pc}), recharging powers of emergency lighting devices (P_{em}) and F_C, F_O, F_D (described below) [9].

The constant illuminance factor F_C considers the possible reduction in power obtainable by keeping the average illuminance on the work surface constant with an automatic control system with closed loop photosensor.

The occupancy dependency factor F_O depends in turn on two other coefficients, F_{oc} and F_a.

- The occupancy dependent lighting control system factor F_{oc} takes into account the type of switching on, switching off and regulation of the lighting system.
- The absence factor F_a indicates the period of utilization of the system, when the area is without occupants: the closer the F_a value approaches 0, the greater the possibility that the environment is occupied; typical values of this parameter area are collected in the Italian Standard UNI TS 11300:2 [10], in relation to the building's type of use.

The coefficient of dependence on daylight F_D allows the evaluation of energy savings that can be obtained through a correct integration between artificial lighting and natural lighting of indoor environments. F_D is calculated in five steps:

- The building is divided into areas with (A_D) or without (A_{ND}) daylight.
- The impact of the parameters relating to the rooms, the geometry of the facade and the presence of external obstructions on the natural lighting of the inside spaces is estimated through the daylight factor.

- The energy saving potential is estimated as a function of the climate, the minimum requirements of illuminance and the daylight factor.
- The exploitation of available natural lighting is determined according to the type of control system [11]
- The monthly values of F_D are determined and then an average annual value can be evaluated.

B. LENICALC

The LENICAL software [4] calculates the LENI (Lighting Energy Numeric Indicator), according to the complete method of the EN 15193 standard, and guides the user [12], step by step, in entering the input data to correctly determine the various parameters required to calculate the LENI, in strict accordance with the standard.

In particular, in the calculation procedure it is necessary to identify within each room the areas that benefit from natural light (A_D area) and those that do not benefit from it (A_{ND}) to calculate Daylight Factor (D) and factor indicating dependence on daylight (F_D).

Once the installed power for the lighting systems in each zone has been defined, it will be necessary to indicate the time of use of the rooms (T_D and T_N), the occupancy index (F_a) and the time of the total installed power when constant illuminance control is in operation (Fc). All these parameters, together with the availability of natural light, will quantify the energy consumption for artificial lighting.

Finally, all the control strategies defined by the standards for daylight and occupancy have been implemented in the LENICALC software. To calculate the energy consumption of the lighting systems, the values of the tables of the EN 15193 standard have also been implemented with the indexes F_C, F_D and F_O.

The initial project phase with LENICALC software, consists of entering the following general properties:

- Maintenance Factor;
- use of the building;
- Latitude, Longitude, Light Exposure;
- Year of Construction;

LENICALC software then allows the import, in dxf format, of the building plan (for each level). The floor plan is then subdivided by creating "rooms" and, for each room, you must to specify:

- main activity carried out in the room;
- room maintenance factor;
- height of the work surface;
- hours of operation in the presence of natural light (T_D);
- hours of operation in the absence of natural light (T_N).

Within the individual rooms it is possible to choose whether to create a single zone or several arranged zones, based on the internal arrangement of the lighting devices and their operation. In the software, for each zone, it is necessary to specify:

- standard average illuminance (E_m);
- real average illuminance (E_m);
- type of presence-based control system (occupancy sensors);
- type of control system based on daylight (photo sensor) (Fig. 2));
- absence factor.

The next step consists in inserting, within the "window" section, the transparent elements and in particular:

- Geometric dimensions of the window;
- Light transmission factor of the glass;
- k1, reduction factor as a function of the frame;
- k2, reduction factor as a function of dirtiness;
- k3, reduction factor for not normal light incidence;
- obstruction angles: θ, α and β (Fig. 3).

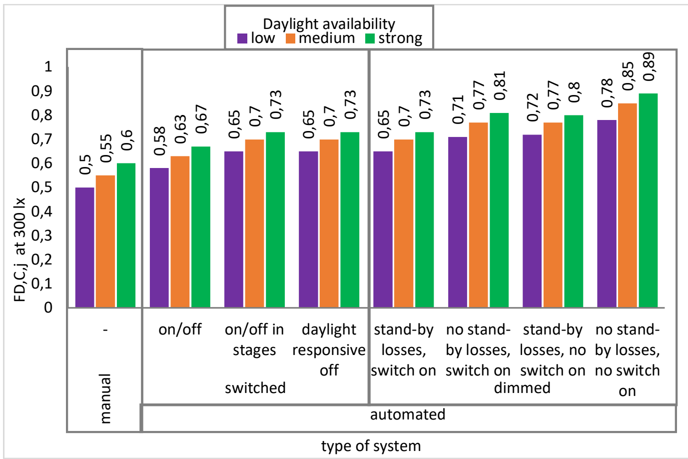

Fig. 2. Daylight dependent artificial lighting control F_{DCi} of the different control strategies and daylight availability.

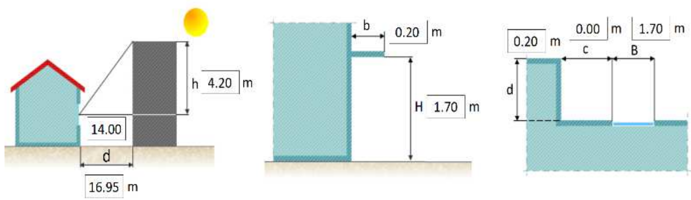

Fig. 3. Angles θ – α – β

The software automatically calculates the areas illuminated or not by natural light, respectively “day light zone” (A_D) and “non-day light zone” (A_{ND}), in which the relative luminaires with their respective powers are inserted.

The LENICALC software results are related to the energy needs for lighting, namely the:

- LENI building;
- specific energy of the building (monthly);
- LENIsub of the floor;

- specific energy of the floor (monthly);
- LENIsub of the room;
- specific energy of the room (monthly).

II. CASE STUDY: BRANCACCIO

The case study analysed in this paper is the Retirement Home “Brancaccio”, located in Matera, Italy (latitude: 40.7°N). The building, dating back to the ‘70s, is 5 storeys building, 7500 m^2, and it can accommodate 250 people (guests and healthcare professionals). Inpatient / elderly people rooms are located in the 3 upper floors, in different sub-blocks according to the health, needs and self-sufficiency level of the guests. The lower 2 floors include common rooms of “Centro diurno polifunzionale” and the offices of “fondazione Brancaccio”, “Il Sicomoro” and “Associazione amici del cuore” associations. In Fig. 4 the Brancaccio building with its lighting system is represented.

Fig. 4. The Brancaccio retirement home with the actual lighring system

The heating systems have been installed starting in 2016, during an energy retrofit of the whole structure. The thermal power plant is located in the ground floor and includes an hybrid plant with condensing boiler and heat pump, dedicated to space heating and hot water production. In six rooms, multi-split type air conditioners (i.e., variable refrigerant flow control VRV) provide Heating, Ventilation & Air Conditioning (HVAC). The third floor is provided with an independent thermal power plant on the flat roof, including two gas condensing boilers and a compression cooling unit. Thermal solar collectors and photovoltaic modules, located on the flat roof, increase the overall efficiency of the whole technological system.

Almost all the rooms benefit from daylight, thanks to several windows (with double glass, light transmittance τ = 81%). Useful area of the building is 6495 m^2, with a glazed area of 1090 m^2 (i.e., 17%).

Luminaires are ceiling mounted and, in the first four floors, are equipped with LED, light emitted sources. In the inpatient’s rooms of the upper floor, the luminaires are equipped with fluorescent tubes. Controls are always manual ON/OFF, both for occupancy and daylight contribution.

The lighting system complies with the standard comfort requirements. A simulation (with software Dialux evo 9.1) has been performed (Fig. 5), resulting in an E_{avg} of about 130 lux in the inpatients rooms, and 200 lux for bathrooms.

The case study has been simulated with LENICALC software (Fig. 6) to evaluate the monthly specific energy for lighting and LENIsub values for the individual rooms and floors have been compared.

A detailed analysis has been performed on a single inpatient room, assuming a LED base system with 101 W of installed power and E_{avg} = 130 lux (from Dialux simulation), in order to determine the influence of the different factors on LENI. In particular, the use of control logics and the shadowing angles related to the floor and orientation have been considered.

Fig. 5. Rendering of inpatients’ room from Dialux simulation.

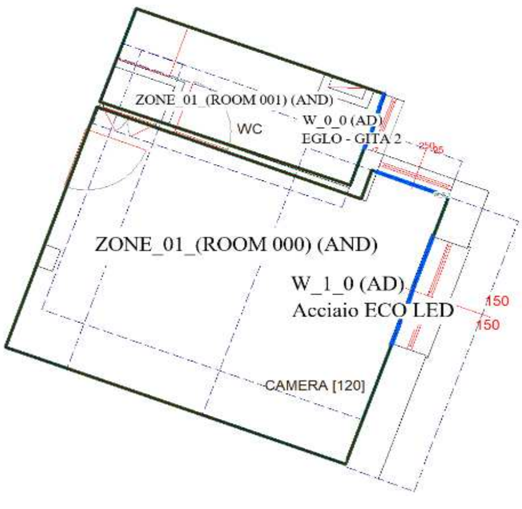

Fig. 6. Inpatients room in LENICALC.

III. RESULTS

The following tables show the simulation results for the entire building and for the individual patient room.

A. BUILDING AND FLOOR CALCULATION

TABLE I. LENI INDEX

	Installed power [W]	Building area [m^2]	Annual building energy [kWh]	LENI [kWh/m^2 year]
Building	24522.10	6494.5	83879	12.92

TABLE II. LENI$_{SUB}$ INDEX VALUES

	Installed power [W]	Floor area [m^2]	Annual floor energy [kWh]	LENIsub [kWh/m^2 /year]
Ground floor	4939.8	1478	20440	13.83
Mezzanine floor	5707.1	1470	16967	11.54
floor 1	3667.5	1340	9951	7.43
floor 2	3667.5	1340	9951	7.43
floor 3	6540.2	866	26568	30.68

The following consideration can be made:

- The value of the LENI$_{sub}$ on the third floor is much higher than on the other levels; this is due to a higher installed power per unit, using the fluorescent sources.
- The monthly specific energy reaches the highest values in December (red) and the lowest values in June (green), corresponding to the periods of the year with lower and higher availability of natural light (±7-8%).

TABLE III. MONTHLY SPECIFIC ENERGY FOR ARTIFICIAL LIGHTING

	Floor monthly specific energy [kWh/m^2/month]				
	Ground floor	**Mezzanine floor**	**Floor 1**	**Floor 2**	**Floor 3**
Jan	1.17	0.99	0.63	0.63	2.61
Feb	1.16	0.97	0.62	0.62	2.57
Mar	1.15	0.95	0.61	0.61	2.54
Apr	1.14	0.94	0.61	0.61	2.52
May	1.14	0.94	0.60	0.60	2.50
June	**1.13**	**0.94**	**0.60**	**0.60**	**2.50**
July	1.14	0.94	0.61	0.61	2.51
Aug	1.14	0.95	0.61	0.61	2.52
Sept	1.15	0.96	0.62	0.62	2.55
Oct	1.16	0.97	0.62	0.62	2.58
Nov	1.18	0.99	0.64	0.64	2.63
Dec	**1.19**	**1.02**	**0.65**	**0.65**	**2.68**

Another important consideration concerns the dynamics of mutual influence between the different energy consumptions. The greater power installed on the third floor for artificial lighting, due to the use of fluorescent sources, determines a greater contribution of thermal energy in the environment compared to the lower floors. This translates into less energy being consumed for heating in winter and more energy being consumed for cooling in summer. Higher consumption for lighting means higher EPL (Energy Performance for Lighting) and consequently lower EPH (Energy Performance for space Heating) and higher EPC (Energy Performance for space Cooling). As a result, the monthly trends of the performance indexes for summer cooling and winter heating are significantly influenced by the monthly variations of the LENI index and the energy performance index for artificial lighting [13]. This dynamic of mutual influence is particularly evident in the presence of fluorescent or incandescent luminaires, for which the heat emitted into the environment is much greater than for LED luminaires.

B. SINGLE PATIENT ROOM CALCULATION

The use of efficient control logics for the lighting systems has a relevant impact on the final consumption of electric energy for artificial lighting; the control logics in use for "Brancaccio" retirement home are manual ones. Assuming the use of different control logics based on occupancy and natural light, with the installation of infrared sensors and photo-sensors, the new LENI$_{sub}$ values relative to a single patient room were calculated. In particular, six different scenarios were simulated, choosing among the different control logics (Fig. 2), those for which the values of the F_{OC} and $F_{DC,n}$ factors were as far apart as possible; in Fig. 2, F_{DC} is low for manual control system, then both F_D and LENI are higher because natural light is lower.

From the results in Table IV, it can be seen that the lowest LENIsub value is reached in scenario 3 ("manual on/off" control logic for occupancy and "dimmed, no stand-by losses, no switch on" control logic for daylight). In this case the energy demand value for lighting is also lower than the scenario where a more efficient control logic is chosen for occupancy control (scenario 6).

TABLE IV. TABLE IV LENISUB CALCULATION

Occupancy	N°	Natural light	LENIsub kWh/(m^2 y)
MANUAL ON – OFF	1)	Manual	27.26
	2)	Daylight responsive off	24.63
	3)	Dimmed, No stand-by losses, no switch on	**23.34**
MANUAL ON - AUTO OFF	4)	Manual	27.43
	5)	Daylight responsive off	25.42
	6)	Dimmed, No stand-by losses, no switch on	24.10

At a first glance it may seem strange that the use of a completely manual logic for occupancy provides better results than an automatic one; it is necessary, however, to consider the behaviour of the users and the intended use of the space; in the patient rooms the presence of people is always expected (Fa=0) and the installation of infrared sensors for presence detection, which constitutes a stand-by power for the system, does not lead to savings in terms of energy demand.

On the other hand, the choice of an efficient daylight control logic has a greater influence on the final value of LENIsub. Comparing scenario 1 (manual), with scenario 3 (automatic), a maximum saving in terms of annual energy demand for lighting of about 14 % is achieved.

Finally, the influence of shading on the LENI value was evaluated, assuming a change in the value of the frontal obstruction angle θ (Fig.7), due to the presence of obstacles and/or neighbouring buildings. In the absence of frontal obstructions (value of θ = 0) the LENIsub of the room is 20.87 kWh/m^2/year; for θ between 20° and 40° the LENIsub value is slightly less than 23 kWh/m2/year, while from 45° to 65° the LENIsub value increases until it reaches 27.04 kWh/m^2/year, a value of about +30% for which the patient room is never illuminated by natural light.

Actually, it is worth bearing in mind that the results in Fig. 7 depend on an approximation of the method provided by EN 15193-1. The standard for the evaluation of the daylight factor considers mainly geometric parameters and then the monthly direct and diffuse components of light is still not accurate; it has therefore been noted that, in this condition, the incidence of obstructions on the energy consumption for artificial lighting is minimal.

Moreover, for the "Brancaccio" retirement home, the values of the frontal obstruction angles θ, hardly exceed 20°

and consequently there are not great differences in relation to the floor of location of the rooms. Conversely, in the presence of nearby obstacles and therefore of high obstruction angles, the energy requirement for lighting increases significantly (the availability of daylight decreases).

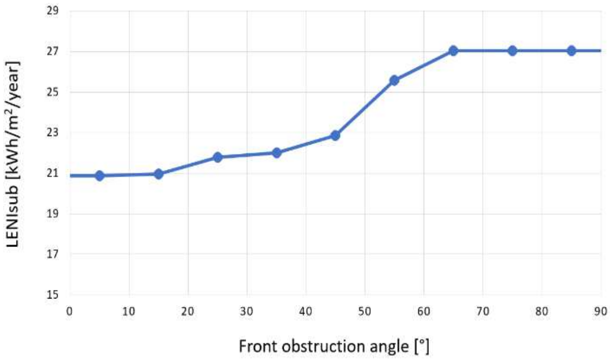

Fig. 7. LENIsub values as function of θ

IV. Conclusions

This work applies the standard EN 15193 and the new software LENICALC for the evaluation of lighting consumption. The main novelty of this work is that lighting consumption is assessed with a monthly method instead of an annual one and this methodology is applied to a particular case study which is a retirement home.

This methodology is very useful because it allows to better evaluate the monthly variation of daylight and the effectiveness of the different control systems. It was possible to evaluate the assumptions of standard EN 15193 and LENICALC analysing the results in different conditions.

The LENICALC software as a design tool was developed to be, on the one hand, flexible and accurate in order to evaluate the effectiveness of all lighting technologies but also user-friendly and fast in order to be used as a decision-making tool.

The results of this work show that:

- the monthly method highlights how consumption for lighting can vary significantly during the year, especially with control systems;
- especially for new nearly zero energy buildings, this methodology could be very useful to be adopted also for residential buildings and for the energy certification of buildings too;
- with the LED lighting sources, consumption is greatly reduced, even more with the control systems but this methodology allows an accurate evaluation of the energy saving potential;
- the regulatory choice of using the luminous exposure obtained from H_{dir}/H_{glob} (tabular values for some latitude ranges only) underestimates the positive effect of some design choices (e.g., shading devices and orientation);
- in applying this methodology, some data on lighting appliances that are not yet available in the technical data sheets (e.g., the Light Output Ratio LOR: the ratio of the luminous flux of the luminaire to the lumens of the lamps used (EN 13032/2);
- LENICALC software is a very useful design tool, work is still being done to make it easier to use (e.g., it will be possible to import dxf files with geometrical information).

V. Acknowledgments

Within the National Research Project starting in 2015, the LENICALC software was developed by ENEA. In the context of Program Agreements 19-21 "Research on the electricity system" between ENEA and the Ministry of Economic Development and, in particular, in Project 1.7 "Technologies for the efficient penetration of the electricity vector into end uses" the current version of the LENICALC software has been funded. Starting in 2022, the new web version of the LENICALC software will be available at https://www.pell.enea.it/enea/.

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